BIRLA CENTRAL LIBRARY
PILANI [RAJASTHAN]

Class No. 671

Book No. K 922 W

Accession No. 32895

Acc. No... ... .

ISSUE LABEL

Not later than the latest date stamped below.

WELDING TECHNOLOGY

To
MY FATHER

WELDING TECHNOLOGY

F. KOENIGSBERGER
Dipl-Ing., M.I.Mech.E.
M.Inst.W., Mem.A.S.M.E.
Lecturer in the College of Technology
and in the University of Manchester

With 214 *photographs and*
diagrams, and 42 *tables*

LONDON
CLEAVER-HUME PRESS LTD.

CLEAVER-HUME PRESS LTD.
42a SOUTH AUDLEY STREET
LONDON, W.1
All rights reserved
First published 1949

By the same Author
DESIGN FOR WELDING
(Longmans, Green & Co., Ltd.)

Printed and bound in Great Britain
at the St Ann's Press, Timperley, Altrincham

PREFACE

THE engineer who has to take charge of welding in its various methods and innumerable applications needs a combined knowledge of general mechanical engineering, electrical engineering, metallurgy, chemistry and—perhaps also—production engineering.

While the fundamentals of the above subjects can be studied, however, from specialized text-books, the author has here attempted to deal with their application to the work of the welding engineer in the shop. As an example, the welding engineer is not expected to design a D.C. arc welding generator or the control circuit for a resistance welding machine, to develop filler rod materials or electrode coatings for use with special materials or procedures, but he has to know how the welding machines work, if he intends to use them and to look after their maintenance, and how to choose filler rods and fluxes, how to use them, and how to judge their effects.

It is hoped that the book, by covering these latter points, may be a guide to students and a help to engineers in industry.

The author is indebted to the firms who have provided photographs, drawings, and general information on their products, and given permission to reproduce extracts from their own publications.

In this connection he would like to acknowledge particularly the co-operation of the following: A.1 Electric Welding Machines Ltd., London; The British Oxygen Company Ltd., London; The British Thomson-Houston Co., Ltd., Rugby; Cooke and Ferguson Ltd., Openshaw, Manchester; Cyc-Arc Limited, London; Hancock and Co. (Engineers), Ltd., Croydon; Imperial Chemical Industries Ltd., Alkali Division, Northwich, Cheshire; Imperial Chemical Industries Ltd., Billingham, Co. Durham; The Lincoln Electric Company, Cleveland, Ohio, U.S.A.; Metropolitan-Vickers Electrical Company Ltd., Trafford Park, Manchester; Murex Limited, Rainham, Essex; Murex Welding Processes Ltd., Waltham Cross, Herts; Safety Products Ltd., London; Sciaky Electric Welding Machines Ltd., Slough, Bucks; Wilkins and Mitchell Ltd., Darlaston.

The kind co-operation of many engineering friends is also gratefully acknowledged, in particular that of Mr. F. Howarth, M.Inst.W., who gave numerous valuable suggestions in connection with the practice of fusion welding procedures, Mr. J. W. Sheldon, A.M.I.E.E., who co-operated untiringly on the chapter dealing with electronic controls of resistance welding machines, and Mr. E. Johnson, B.Sc., A.M.I.Mech.E., who kindly read through the whole script and the proofs.

Messrs. Cleaver-Hume Press Ltd., London, gave permission to use parts of the author's contribution to their book on *Modern Workshop Technology.*

Finally, the author's father, although himself not an engineer but gifted with profound engineering sense, has, by his continued interest and encouragement, greatly assisted in the work on the book.

F. KOENIGSBERGER

Manchester, January 1949.

CONTENTS

Chapter *page*

I. GENERAL SURVEY OF WELDING PROCESSES AND THEIR APPLICATION 1
Advantages and Limitations. Principal Types of Welding, and their Characteristics.

II. FUSION WELDING PROCESSES 12
Oxy-acetylene Welding. Electric-arc Welding. Carbon-arc Welding. Argon-arc Welding. Metal-arc Welding, including Automatic and Stud Welding.

III. FUSION WELDING PROCESSES (*continued*) 67
Atomic Hydrogen Welding. Thermit Welding.

IV. FORGE WELDING PROCESSES 76
Principal Features. Current and Pressure Control. Resistance Welding Machines. Seam Welding. Projection Welding. Flash Butt Welding. Special Devices. Testing.

V. WELDING FERROUS METALS 103
Weldability. High tensile steels. Stainless steels. Cast steel. Cast iron. Hard facing.

VI. WELDING NON-FERROUS METALS 118
Copper and its alloys: Aluminium and its alloys. Magnesium alloys.

VII. PLANT AND EQUIPMENT FOR OXY-ACETYLENE WELDING 129
Gas-producing and storing Plant. Pressure regulators. Blowpipes.

VIII. EQUIPMENT FOR ARC WELDING 145
D.C. Generators for Welding. A.C. Transformers. Arc Stud Welding Equipment. Atomic Hydrogen Welding Equipment.

IX. ELECTRICAL EQUIPMENT FOR RESISTANCE WELDING 163
Transformer Equipment. Timing Devices. Electronic Control Systems.

X. FLAME CUTTING AND GOUGING 185
Equipment and Technique for Flame Cutting. Flame Gouging.

Chapter *page*

XI. WELDING MANIPULATORS AND FIXTURES 205

XII. SAFETY PRECAUTIONS, PROTECTIVE AND WELFARE EQUIPMENT 218

XIII. PLANT MAINTENANCE 223

XIV. DISTORTION AND RESIDUAL STRESSES 227

XV. WELD STRENGTH AND WELD FAULTS 237

XVI. DESIGN PRINCIPLES AND DRAWING OFFICE PROCEDURE IN CONNECTION WITH WELDING 250

XVII. SOME NOTES ON ESTIMATING FOR MANUFACTURE BY WELDING 265

APPENDIX: Some means of Identifying Metals to be Welded 272

AUTHOR INDEX 273

SUBJECT INDEX 274

CHAPTER I

GENERAL SURVEY OF WELDING PROCESSES AND THEIR APPLICATION

Characteristics. Engineering structures and components can be manufactured by casting or forging, or they can be fabricated from a number of smaller components, by riveting, bolting, or welding parts together. Riveted and welded structures take a special place amongst the fabricated structures in so far as—once they have been completed—they cannot be taken to pieces without destruction of the joints.

The weld, which is the connecting element between the components of a fabricated welded structure, has to locate them in relation to each other and to transmit loads which occur under working conditions.

Welding in perfection which will—of course—rarely, if ever, be obtained, has been admirably defined by Dr. W. H. Hatfield, F.R.S., as " the art of joining parts of the same metal in such a way that the result is a continuity of homogeneous material, of the composition and characteristics of the two parts which are being joined together."

During the welding process heat is used to bring about a plastic or molten state at the metal surfaces to be joined, and the methods of heat generation may be: (*a*) *Blacksmith's fire*, (*b*) *Gas* (oxy-acetylene welding, water-gas welding), (*c*) *Electric arc* (carbon-arc welding, metal-arc welding, argon-arc welding), (*d*) *Gas plus electric arc* (atomic hydrogen welding), (*e*) *Chemical reaction* (thermit welding), (*f*) *Electrical resistance* (resistance welding).

Advantages and Limitations. When comparing welding with other methods of construction, both technical and economic aspects must be borne in mind.

Comparison with casting. Taking the case of ferrous materials, the mechanical properties of mild steel and cast steel are generally superior to those of cast iron, with the exception of the vibration damping quality, the sliding quality, and the resistance to wear, in which cast iron is superior to steel.

Moreover, the designer of a casting is liable to find that core displacements during moulding and casting cause variations in the intended wall thicknesses. Fig 1.1 shows the section of an actually fractured cast iron press frame where the top left-hand corner is considerably weakened by core displacement. Such sections have to be designed stronger than theoretically required, in order to allow for this possibility. In order to obtain good material-flow during casting wall thicknesses have to be kept above a certain minimum and abrupt changes have to be avoided. This again demands an allowance of more than the theoretically required material. This problem does not exist to any comparable extent in connection with fabricated steel structures.

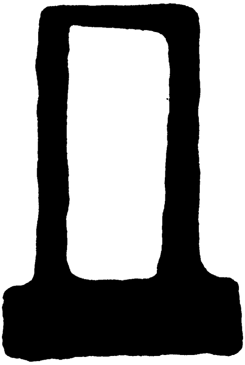


Fig. 1.1

Comparison with riveting. For riveted or for spot-welded assemblies additional flanges must often be provided, which are not necessary in the case of arc-welded assemblies (Fig. 1.2); these often mean a considerable increase in weight of material. In the stress calculation of riveted structures, due allowance must also be made for the weakening of plates and rolled sections by rivet holes. As these are not required in welded structures, smaller sections can be employed.

Locked-up stresses. This problem may become very serious in welded structures. It has to be considered in castings, but does not occur in properly-produced riveted or bolted structures.

Quantity factor. For small quantities the cost of patterns may decide against the use of a casting. If, however, a structure is rather complicated, with a number of little bosses and brackets which would have to be welded separately on to it, the casting may be more economical.

Labour cost. Welding time is the biggest cost factor in a welded structure. Usually the most economical fabricated welded structure is the one which requires the minimum amount of welding. The cost of additional labour can often cancel the possible saving in material.

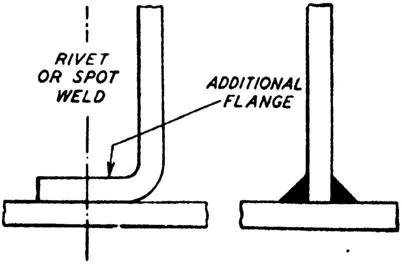


Fig. 1.2

Whilst the above remarks apply to the application of welding in general, the choice of one or the other welding process in particular is dictated by the materials used, and by the type of work and design to which it is to be applied.

Types of Welding. The welding processes generally used are classified into two main groups (Fig. 1.3).

I. FUSION WELDING PROCESSES, i.e. welding without pressure (oxy-acetylene welding, arc welding, atomic hydrogen welding, thermit welding).

II. FORGE WELDING PROCESSES, i.e. welding under pressure (blacksmith welding, water-gas welding, resistance welding).

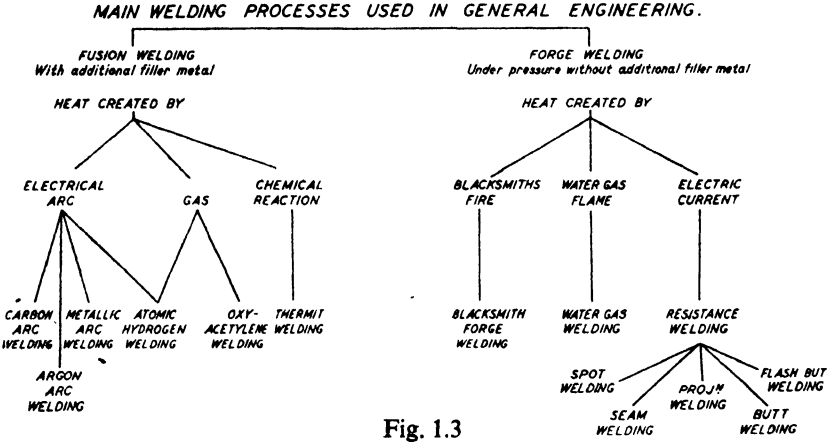


Fig. 1.3

FUSION WELDING PROCESSES

Oxy-Acetylene Welding. The edges of the material to be welded and the filler material are heated up to melting temperature by the gas flame of a blowpipe. The filler material is deposited in the gap between the two parts to be joined, and the molten metals run together, the whole integrating on cooling. Whilst oxy-hydrogen (for welding metals which have a low melting point) and coal-gas flames are also used in certain cases, acetylene, C_2H_2, is the gas mostly used for gas welding. The temperature of the oxygen-acetylene flame is about 3100°C.—higher than that obtained with any other gas.

The acetylene is either generated on the spot from calcium carbide and water, or ready stored in suitable steel cylinders. The low pressure acetylene obtained from a generator is drawn into the mixing chamber and to the nozzle of an injector-type blowpipe by the relatively high-pressure oxygen, whilst acetylene from a steel cylinder reaches the blowpipe mixing chamber through its already relatively high storage pressure. The "high pressure" blowpipes used with this latter method require, therefore, only a chamber where the acetylene and oxygen are mixed before passing through the nozzle.

An important feature of gas welding is that the temperature gradient in the base metal from the zone of fusion to the cold metal distant from it can be controlled by suitably directing the flame during the welding process.

Oxy-acetylene welding is mainly used for welding sheet steel, cast iron, and non-ferrous metals.

Electric-Arc Welding. The arc welding processes use the heat of an electric arc for melting the base material and also the filler metal when used. The arc may be struck either between (a) two carbon electrodes, (b) a carbon electrode and the base material, (c) a tungsten electrode and the base material, or (d) a metal electrode and the base material, the metal electrode in this case providing at the same time the filler material. The types of electric-arc welding are as follows:

(1) CARBON-ARC WELDING (Fig. 1.4.). This was the first electric-arc process to be developed and uses carbon electrodes and a rod or wire of filler material. To obtain good metal flow during the welding process, and prevent impurities from the air reducing the quality of the weld, a flux is generally employed. This process is used for welding sheet steel, copper alloys, brass, bronze and aluminium. High welding speed and efficient welds are the main advantages claimed.

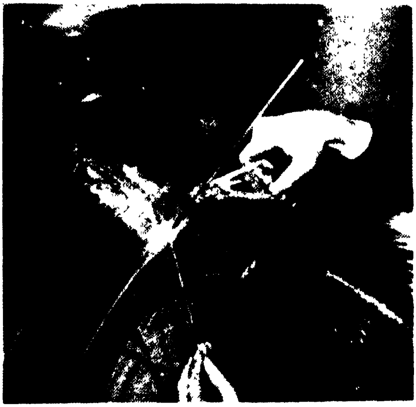


Fig. 1.4. Carbon-Arc Welding (*Lincoln Electric*)

(2) ARGON-ARC WELDING (Fig. 1.5). The heat source in the argon-arc welding process is an electric arc between a tungsten electrode and the parent material. The electrode is mounted centrally in a nozzle-shaped hood through which an inert gas, argon,[1] is passed, which shrouds the arc and prevents any action of atmospheric elements on the molten metal. The argon shield eliminates the need of using fluxes which, particularly in the case of welding light alloys, often cause corrosion of the welded zone.

Standard welding machines are used for supplying the arc welding current. The argon gas is usually stored ready for use compressed in steel cylinders. In general filler rods are used. Argon-arc welding can be used for welding light alloys, monel metal, inconel, brass, and stainless steel.

---

[1] In the U.S., Helium instead of Argon is used, hence the similar process is called Helium-Arc Welding.

(3) METAL-ARC WELDING. This is the arc welding process most frequently used in general engineering. The arc, drawn between the filler metal electrode and the plate material to be welded, creates a temperature of over 3500°C. in a small area concentrated at the point of welding on the plate and at the end of the filler rod. Whilst the surface of the base metal is molten and ready for welding, the end of the filler rod also melts, and small drops of molten filler metal are projected through the arc on to the welding point, to unite with the base metal.

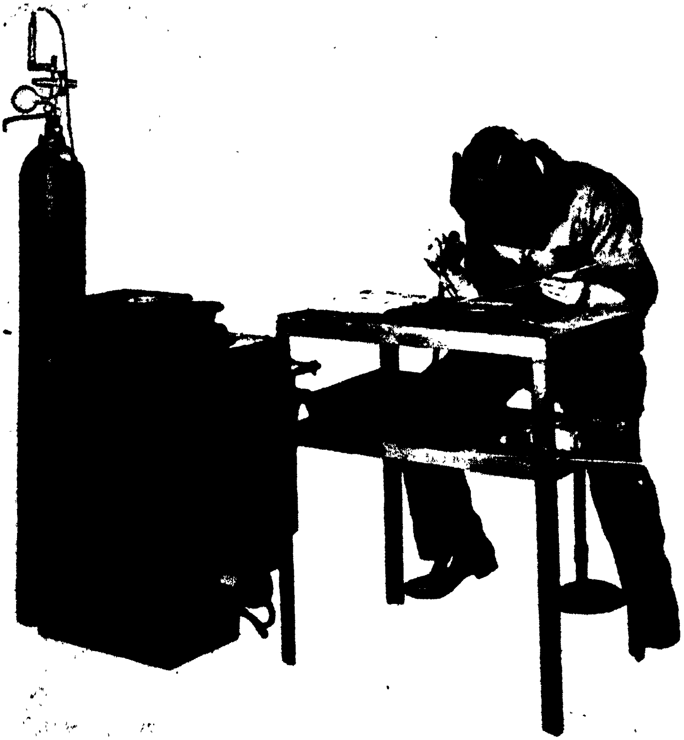


Fig. 1.5. Argon-Arc Welding (*B.O.C.*)

Most metals can be welded by this process, but its main application is in the welding of all kinds of steel up to the heaviest sections, the lower economical limit being about ⅛″ thickness of material.

Atomic Hydrogen Welding. Hydrogen normally exists in molecules of two atoms, but this process[1] is based on the possibility of obtaining atomic hydrogen in the form of single atoms by means of an electric arc between two tungsten electrodes, in an atmosphere of hydrogen at atmospheric pressure. The recombination of the atoms, which occurs in the cooler regions immediately outside the arc, produces a temperature of the order of 3760°C., as compared with 2860°C. produced by the combination of normal hydrogen with oxygen. Further, the very great heat conductivity of hydrogen at high temperatures, due to the dissociation of the hydrogen molecules into the atomic state, results in an extremely high rate of delivery of heat to the surfaces to be welded—approximately twice that for the oxy-acetylene welding flame.

The reducing atmosphere of hydrogen surrounding the arc prevents contamination of the weld, and, due to the highly concentrated heat, high welding speeds may be obtained, keeping distortion small.

The welding torch carries the two tungsten electrodes and the hydrogen nozzle. The hydrogen is usually supplied from steel cylinders, or obtained from anhydrous ammonia by means of an ammonia cracker. Filler rods are generally used. Atomic hydrogen welding is most satisfactory where the advantages of gas welding (control of heat distribution) are to be combined with high welding speeds. It has proved advantageous in welding alloy steels, as—apart from a certain loss in carbon (see page 70) no other alloying elements are lost during the welding process. It is also successfully applied for welding stainless steel, probably due to the reducing character of the arc flame. The high temperature obtained makes it possible to weld heavy sections and to make small deposits on large masses of metal (building up of edges of dies, see page 116). Most non-ferrous metals can also be successfully welded.

Thermit Welding (Fig. 1.6). The thermit welding process makes use of the high affinity of oxygen to aluminium, so that, in a chemical action between the oxide of, for instance, iron, and aluminium, the oxygen combines with the aluminium with a very considerable evolution of heat, and the iron is left in an almost pure and molten state and at a very high temperature.

For welding steel, a mixture (Thermit) of aluminium and iron oxide is placed in a mould which, in its lower portion, embraces the surfaces to be joined and is ignited by a special ignition mixture ($Ba_2O_2 + Al$).

---

[1] See I. H. Hogg, " Atomic Hydrogen Welding," *Metropolitan-Vickers Gazette,* October 1945, and Langmuir, *Industrial and Engineering Chemistry,* June 1927.

The reaction is: $3Fe_3O_4 + 8Al = 4Al_2O_3 + 9Fe$

Iron oxide + Aluminium = Aluminium oxide + Iron

and the temperature during the reaction is about 3000°C. The ends of the base metal to be welded are brought to their melting temperature by the heat of the reaction, the "Thermit" iron fills the surrounding mould, and the whole then solidifies as a single unit on cooling. The weld consists of practically pure iron covered by slag (aluminium oxide) which is subsequently removed.

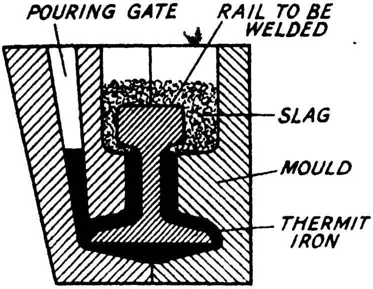


Fig. 1.6

Thermit welding is used for repair work on heavy components, such as castings or forgings, the butt welding of pipes and bars, and particularly of rails, since this process can be carried out on site.

FORGE WELDING PROCESSES

Blacksmith Welding (Fig 1.7). This is the oldest of all welding processes. The parts to be welded are heated in the blacksmith's fire to white heat and then forged together by hammering (hand, steam-hammer, etc.) or pressing (hydraulic press). Butt welds (*a*) and overlapped welds (*b*) can be obtained, and in case of material of larger thickness the edges of parts to be welded are chamfered and a wedge-shaped filling piece, also at welding heat, is forged into the gap (*c*).

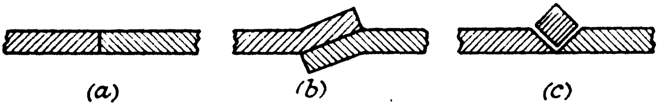


Fig. 1.7

For welding pipes and vessels with large wall thicknesses water-gas is sometimes used. This consists mainly of hydrogen and carbon monoxide with impurities of carbonic acid and nitrogen. The burners, which are usually applied in pairs to both sides of the plates to be welded, are supplied with water-gas and air under pressure. The flame temperature is about 2000°C. After the plate edges to be welded have been brought up to welding heat, the actual forge welding is carried out by hand or power hammer, under the hydraulic press, or by means of hydraulically operated pressure rolls. The latter are particularly used for automatic welding of large boiler drums (Fig. 1.8).

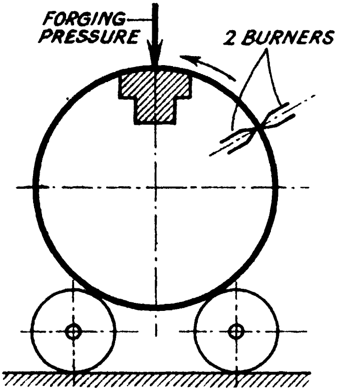


Fig. 1.8

This process produces very sound and reliable welds, the formation of oxides in the welded zone being prevented by the reducing characteristic of the gas. It is, however, used only in special cases such as boiler welding, because of the rather expensive generating plant and the welding machinery required.

Resistance Welding. In the various resistance welding processes, the welding heat is generated by the resistance to an electric current, passing through the components to be welded together, at the point or points to be welded. No additional filler material is used, but pressure is applied during the welding operation.[1]

The heat generated is proportional to the time of current-flow

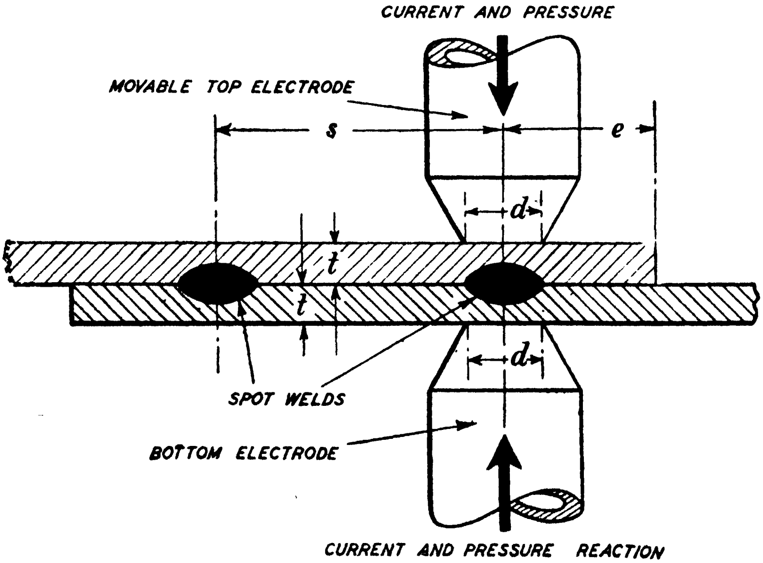


Fig. 1.9

---

[1] See *Welding Memorandum No. 4c*, Advisory Service on Welding, Ministry of Supply, London (published by H.M.S.O.); American Welding Society's *Welding Handbook*, 1942; and *Resistance Welding Manual*. published by the Resistance Welder Manufacturers' Association, Philadelphia, U.S.A.

~~and~~ to the square of the current itself. (In the case of flash butt welding, additional heat is obtained from the flashing arc which is drawn during the process.)

Most engineering materials can be resistance welded. Special control gear is required, however, in the case of high carbon steels, and special equipment providing very high current impulses (*stored energy welding*) is used for welding materials of low electrical resistance.

(1) Spot welding (Fig. 1.9). The plates to be welded together are clamped between two electrode tips (copper or copper alloy) which pass the welding current through the plates. Due to the high heat-conductivity of copper, the heat generated by the current is rapidly transferred from the outer faces of the plates to the electrodes, which are water-cooled; but only slow heat dissipation can take place from the inner faces at the points where welding is to take place, the heat conductivity of steel being approximately 10 per cent of that of copper. The plates are thus forged together over an area corresponding closely to that of the electrode tips (diameter *d*).

Spot welding is applicable for joining components made from plate material, the plate thickness (*t*) being limited by the pressure and current capacity of the available spot-welding machine.

(2) Seam welding is a process which makes a series of either spaced or overlapping spot welds by means of rotating wheel electrodes. If the spots are overlapping, gas-tight joints are obtained.

(3) Projection welding (Fig. 1.10). The position and size of

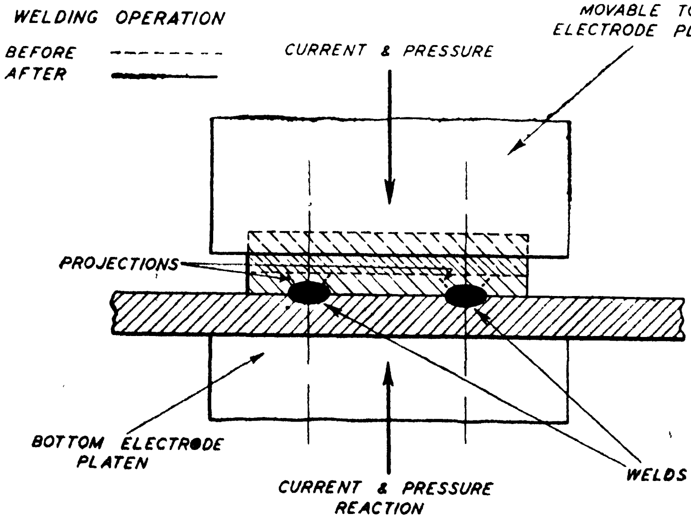


Fig. 1.10

contact faces to be welded are, with this process, not determined by the electrodes but by the design of the components, one or more of which are provided with projections. The electrodes are platens of large surface, the current density being determined by the size and number of the projections. Projection welding is advantageous for joining in large quantities relatively small components made of plate material, and for welding studs, nuts, or bosses to plates, the speed of operation exceeding that of any other welding method.

(4) BUTT WELDING (Fig. 1.11). The heat required for butt welding is generated by the contact resistance between the two components, the faces of which have to be machined or prepared. Pressure and current are maintained throughout the operation, the pressure being gradually increased up to the value which will forge the two pieces together. The method, which has the advantage of creating a smooth and symmetrical upset and no flash spatter, is mainly confined to the welding of wires or thin flat material (e.g. band-saw blades).

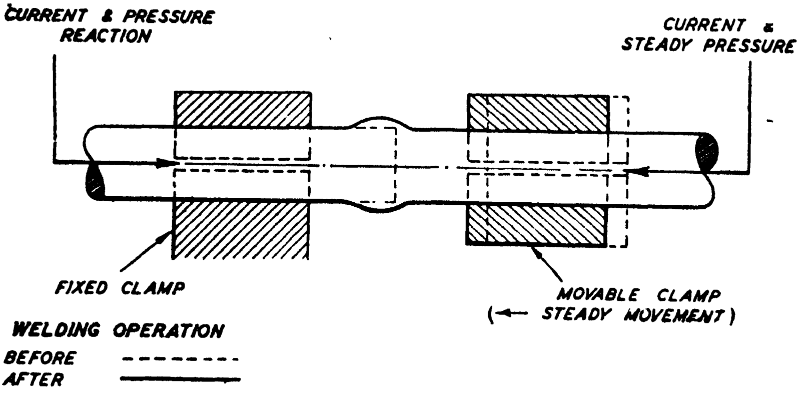

CURRENT & PRESSURE REACTION
CURRENT & STEADY PRESSURE
FIXED CLAMP
MOVABLE CLAMP (← STEADY MOVEMENT)
WELDING OPERATION
BEFORE --------
AFTER ————

Fig. 1.11

(5) FLASH BUTT WELDING (Fig. 1.12). Here the flashing action which creates the heat required is developed in the following way. Protruding small parts of the faces to be welded are brought into contact, and the heat generated owing to the high resistance of the contact areas raises the temperature of the material at these points and causes them to melt. The molten metal is blown out, and a small arc is formed, which raises the temperature of adjoining parts of the abutting surfaces. The ejection of molten metal from high spots continues until the whole of the surfaces are heated to the welding temperature. Some additional heat may be created by the combustion of molten particles, the forcible ejection of which is probably due to the pressure of metallic vapour. The flashing action is aided by

an oscillating movement of one of the components. As soon as the whole of the surfaces to be welded reach forging temperature, the forging pressure is applied, and the current is cut off.

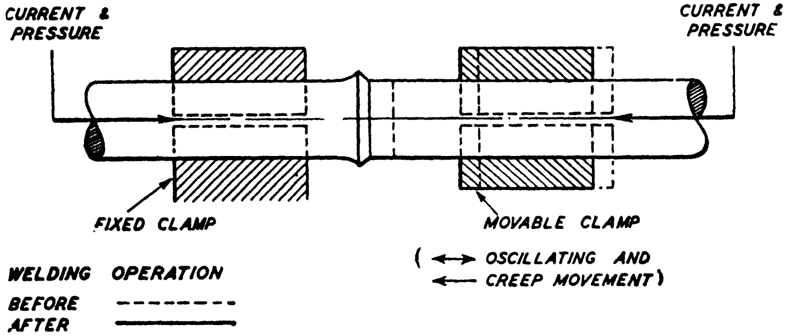


Fig. 1.12

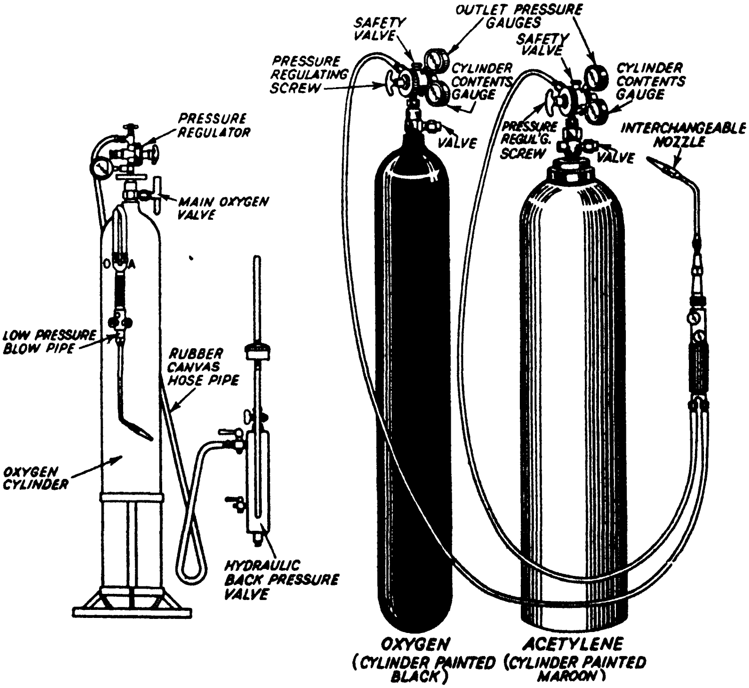
Flash butt welding creates a joint which has under static loading practically the full strength of, and under dynamic loads only slightly less strength than, the parent metal. The process is used for butt welding all kinds of rolled sections, pipes, rails, etc., and for welding low carbon shanks to high-speed steel cutting tools.

CHAPTER II

FUSION WELDING PROCESSES

OXY-ACETYLENE WELDING

An oxygen-acetylene flame provides the welding heat required for the process. Typical equipment is shown in Fig. 2.1. Acetylene C_2H_2 is either generated on the spot (low pressure welding, *a*), or ready stored



(*a*) (*b*)

Fig. 2.1. Oxy-acetylene Equipment: (*a*) Low Pressure; (*b*) High Pressure (*B.O.C.*)

compressed to 15 atmospheres in steel cylinders (high pressure welding, *b*). Oxygen is usually stored compressed to 120 atmospheres in steel cylinders. Both gases mix in a blowpipe, and combustion takes place outside the nozzle. The welder usually holds the blowpipe in his right hand, directing the flame so as to heat the portion of metal to be welded. As soon as the metal is near its melting point, he heats up the end of the filler rod in his left hand, and the molten metal from it is added to the molten pool of the parent material. Apart from correct technique, suitable type and size of filler rods (see page 24) and correct adjustment of the flame are essential.

The flame intensity depends upon the quantity of gas passing through the nozzle, and has to be adjusted to suit different welding jobs, especially in relation to the thickness of material to be welded, and hence interchangeable heads with nozzles of different sizes are usually supplied with each blowpipe. High pressure blowpipes (Fig. 2.2) are provided with interchangeable nozzles, and low pressure blowpipes with interchangeable nozzle-heads (Fig. 2.3).

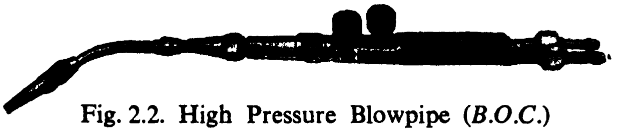
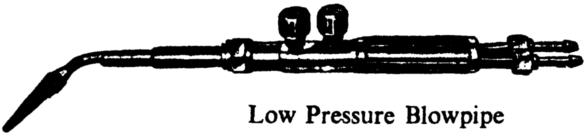
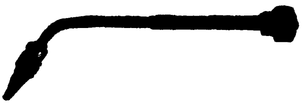


Fig. 2.2. High Pressure Blowpipe (*B.O.C.*)



Low Pressure Blowpipe



Detachable Nozzle-Head (*B.O.C.*)
Fig. 2.3

The gases are stored under high pressure to save space, but are used in the blowpipe at much lower pressure. Reduction valves are provided for this purpose, and are connected to the main outlet valves of the cylinders (Fig. 2.1). They are usually fitted with two pressure gauges, one indicating the gas pressure in the cylinders, the other the reduced outlet pressure. The reduction valves are adjustable and enable the operator to vary the pressure of the outgoing gases in accordance with the welding conditions. (Tables 1 and 2.) Pressure reduction is, of course, only necessary when the gas is stored at high pressure in steel cylinders.

TABLE 1

HIGH PRESSURE BLOWPIPES.

Nozzle sizes for various metal thicknesses, working pressures, and gas consumption[1]

Plate thickness (inches)	Nozzle size	Regulator pressures lb./sq. in. oxygen and acetylene
$\frac{1}{32}$	1	2
$\frac{3}{64}$	2	2
$\frac{1}{16}$	3	2
$\frac{3}{32}$	5	2
$\frac{1}{8}$	7	2
$\frac{5}{32}$	10	3
$\frac{3}{16}$	13	3
$\frac{1}{4}$	18	3
$\frac{5}{16}$	25	4
$\frac{3}{8}$	35	4
$\frac{1}{2}$	45	6
$\frac{3}{4}$	55	8
1	70	10
Over 1	90	14

The nozzle size indicates the approximate consumption of each gas in cubic feet per hour, using a neutral flame at the pressure indicated.

The size of nozzle given for a particular thickness is for general guidance only, and will vary according to the skill of the welder, mass of metal, etc. The capacity of each nozzle overlaps the capacities of those next in size to it. The values given are for underhand butt welds in mild steel. For other techniques, nozzles sizes and pressure may have to be varied slightly; e.g., for copper select a larger nozzle; for aluminium a smaller nozzle.

---

[1] British Oxygen Co., Ltd.

TABLE 2

LOW PRESSURE BLOWPIPES

Nozzle sizes for various metal thicknesses, working pressures, and gas consumption[1]

Plate thickness (inches)	Nozzle size	Oxygen pressure lb./sq. in.
$\frac{1}{32}$	1	7
$\frac{3}{64}$	2	7
$\frac{1}{16}$	3	10
$\frac{3}{32}$	5	12
$\frac{1}{8}$	7	14
$\frac{5}{32}$	10	16
$\frac{3}{16}$	13	18
$\frac{1}{4}$	18	18
$\frac{5}{16}$	25	20
$\frac{3}{8}$	35	22
$\frac{1}{2}$	45	24
$\frac{3}{4}$	55	26
1	70	28
Over 1	90	30

[1] British Oxygen Co., Ltd. See notes below Table 1.

In low pressure welding the acetylene is taken directly from the generating plant, and no pressure reduction is required. But to prevent any flow of oxygen or air from the blowpipe back to the generating plant, low pressure supply lines are provided with hydraulic back-pressure valves (Fig. 2.1) (see also page 134).

After the gases are supplied to the blowpipe at their correctly adjusted pressures, they are brought together in the blowpipe mixing chamber (see page 142).

Flame adjustment. In order to obtain the correct gas quantities in the mixture, hand-operated valves are provided in both gas supply lines of the blowpipe.

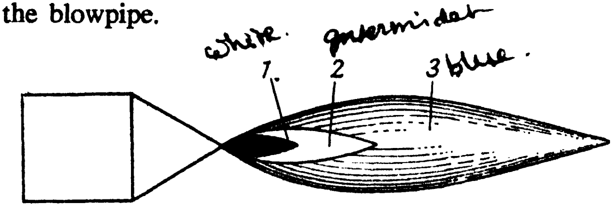


Fig. 2.4

The oxy-acetylene flame (Fig. 2.4) can be divided into three zones in which combustion takes place. In zone 1 the carbon from the acetylene combines with the oxygen to form carbon monoxide, the hydrogen of the acetylene being freed:

$$C_2H_2 + O_2 = 2CO + H_2$$

Acetylene + Oxygen = Carbon monoxide + Hydrogen

In zone 2 carbon monoxide and hydrogen are found in the proportion of 2:1 by volume. If, during the actual welding process, this zone touches the material to be welded, the reducing character of the flame will tend to withdraw oxygen from the welded material and will prevent oxidization. In zone 3 the carbon monoxide and the hydrogen together with oxygen taken from the surrounding air, form carbon dioxide and steam.

$$2CO + H_2 + 3O = 2CO_2 + H_2O$$

Carbon monoxide + Hydrogen + Oxygen = Carbon dioxide + Water

Zone 1 consists of an inner brilliant cone with a darker border in which the first chemical reaction takes place. The hottest temperature will be found just outside the tip of this zone.

The three possibilities of adjustment: equal oxygen and acetylene, surplus oxygen, or surplus acetylene, can be judged by the appearance of the flame (Fig. 2.5). In the carburizing flame (A) no sharp definition between the zones can be observed; it has excess acetylene. The neutral flame (B) shows a clear cone (zone 1) at the torch tip, surrounded by a lighter zone (zone 2) and passing into the surrounding part of zone 3. In the oxidizing flame (C) the brilliant cone (zone 1) is rather small, and zone 2 has nearly completely disappeared. The neutral flame is mostly used for welding steel, but the others have various applications (see pages 25, 119–122).

Whilst the quantities of the gases passing through the blowpipe are adjusted in such a way as to produce a flame of the required chemical properties (usually neutral), careful pressure adjustment is

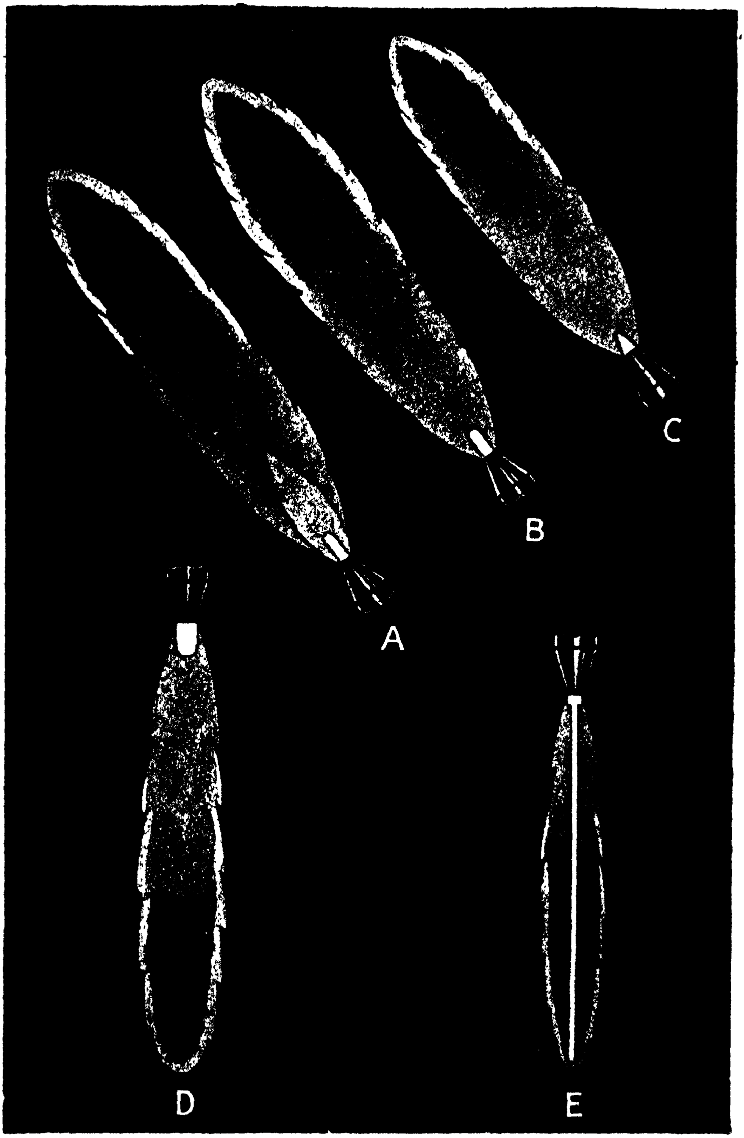


Fig. 2.5. Oxy-acetylene Flames: (A) Carburizing, (B) Neutral, (C) Oxidizing, (D) Preheating for Cutting (see page 188), (E) Cutting (see page 188). (*B.O.C.*)

necessary in order to obtain the correct speed of the outcoming gases at the blowpipe nozzle. Excess speed (too high gas pressure in relation to the nozzle size) produces a "harsh" flame which would not only melt the parent metal but would cause turbulence and displacement of the metal in the molten pool, blowing it away from the weld crater, and causing laminations, adhesions, and lack of fusion in the finished weld.

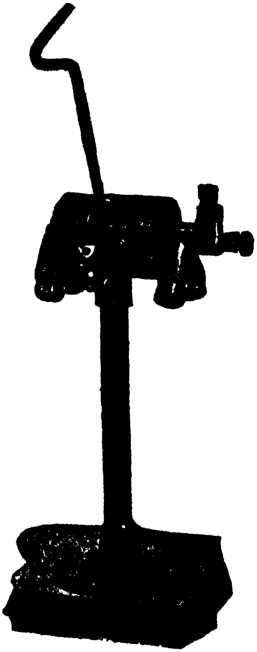


Fig. 2.6. Gas Economizer (*B.O.C.*)

The adjustment of each gas pressure by means of the regulators should be carried out with the corresponding valves in the blowpipe fully open. Otherwise the pressure-reading at the regulators will be higher than in the fully open position of the blowpipe valves and unstable flame conditions will result during the welding operations. Careful handling of the blowpipe, particularly of the burner orifice, will increase its life and efficiency.

"*Lighting-up*". The following procedure should be used for lighting or extinguishing the blowpipe flame:

1. Adjust the oxygen pressure by fully opening the oxygen valve of the blowpipe, and then opening the oxygen cylinder valve and adjusting the regulator, starting with the pressure-adjusting screw fully out, i.e. zero pressure.

2*a*. In the case of *low pressure* equipment, open the acetylene control valve of the blowpipe, with the oxygen valve in the open position. Ignite the gases leaving the burner orifice, the correct flame (Fig. 2.5) being obtained by adjusting the oxygen and acetylene control valves.

2*b*. In the case of *high pressure* equipment, cut off the oxygen supply, and adjust the acetylene pressure by means of the respective pressure regulator. Then ignite the acetylene at the burner orifice, and slowly open the oxygen valve of the blowpipe until the correct flame (Fig. 2.5) is obtained.

3. When extinguishing the flame, always cut off the acetylene first.

To economize on gas consumption when not using the burner, but without upsetting the valve adjustments, so-called gas economizers (Fig. 2.6) are in use. They consist of two valves which are inserted between the gas supplies and the blowpipe, and which are shut down by the downward movement of a lever, as soon as the blowpipe is hooked on to it when not in use.

Filler rods. The material of the filler rods depends on, but is not necessarily the same as, the parent material to be welded. For welding mild steel, for instance, which has been taken as a typical case in the previous examples, the filler rod material contains more carbon, manganese and silicon and less phosphorus and sulphur than the parent material.[1] Manganese and silicon are particularly important as they act as de-oxidizing agents, and improve the tensile properties of the weld metal.

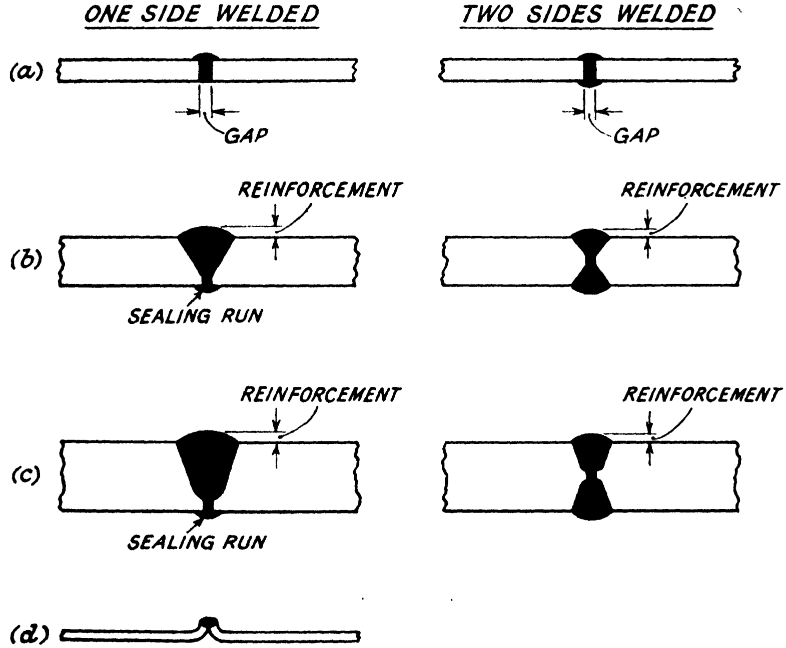


Fig. 2.7

Types of welds. Fusion welded joints can be divided into two main groups, butt welds (Fig. 2.7) and fillet welds (Fig. 2.8). Tee-joints (2.8a), lap-joints (2.8b), or corner joints (2.8c) are the fillet weld connections generally used. Although unnecessary with small plate thicknesses (2.7a), chamfering (2.7b) or gouging (2.7c) of the edges of thicker plates is necessary, if full union for the full depth is to be effected by butt welding (see also page 44). A preliminary bending operation (2.7d) is often used for welding plates of small thickness without the use of filler material. As fillet welds do not usually require plate edge preparation, they are more economical. The shape of the fillet weld, however, creates stress raisers at the root and toe of the weld, a fact, especially important with dynamic loading. The danger of stress concentration is less pronounced in the case of butt welds, especially if reinforcements (Fig. 2.7) are removed mechanically after welding.

---

[1] Information supplied by the British Oxygen Co. Ltd., London.

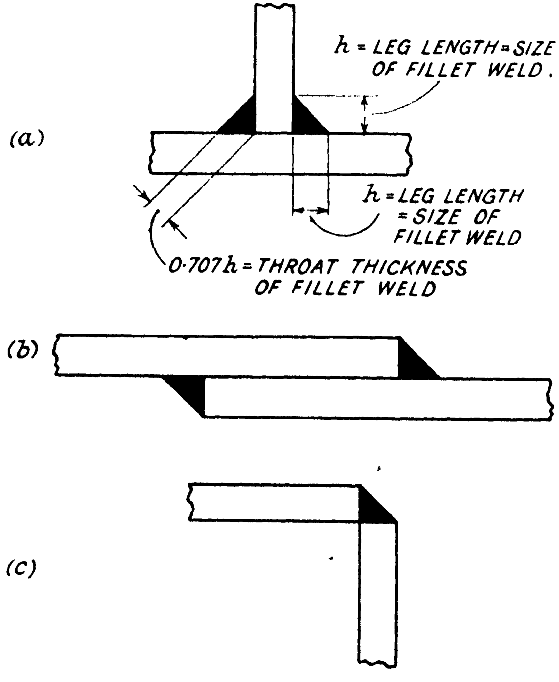

(a)
h = LEG LENGTH = SIZE OF FILLET WELD.
h = LEG LENGTH = SIZE OF FILLET WELD
0·707h = THROAT THICKNESS OF FILLET WELD
(b)
(c)

Fig. 2.8

Welding technique. When laying down the runs of weld metal into the gap (butt welding), or the corner (fillet welding) two typical procedures can be employed. Up to $\frac{3}{16}''$ plate thickness "leftward welding" (Fig. 2.9) is considered most suitable. For thin plates up to $\frac{1}{8}''$ thickness no edge preparation is required, and the blowpipe is moved straight along the edge to be welded at a height where the tip of the brilliant inner cone of the flame is just clear of the molten pool and the end of the filler rod.

For leftward welding plates above $\frac{1}{8}''$ and up to $\frac{3}{16}''$ thickness chamfering of the plate is necessary, and the blowpipe should make an additional, slightly oscillating, movement from side to side, in order to fuse both sides of the vee.

For the welding of thicker plates " rightward welding " (Fig. 2.10) is recommended. Whilst with leftward welding the blowpipe flame points *away* from the deposited molten pool of weld metal, with rightward welding it is directed *towards* it. The brilliant inner cone of the blowpipe flame is pointing deep into the gap between the plates. It should, however, touch neither parent plate nor filler rod. A forward and side movement of the filler rod, describing series of loops as shown, is used for depositing material over the full width of the vee. Fig. 2.11 shows applications and required preparations for welding mild steel with both methods.[1]

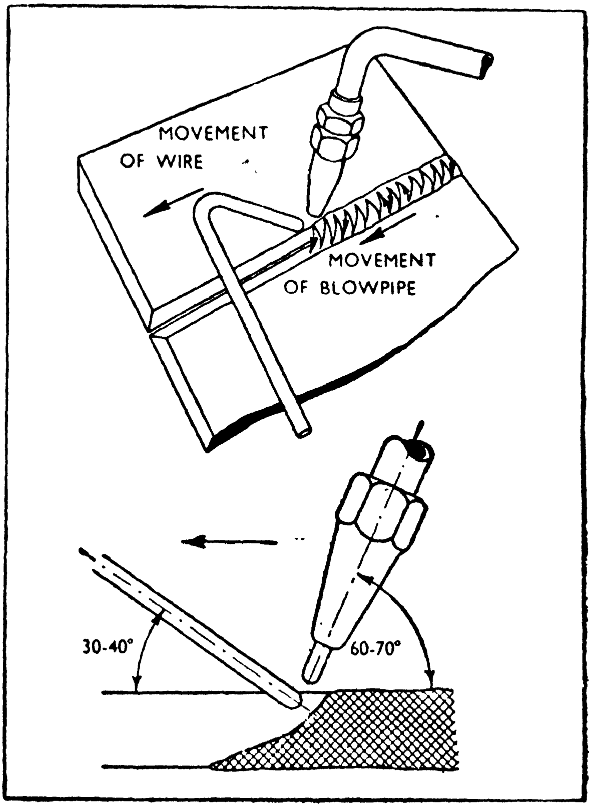


Fig. 2.9. Leftward Welding (*B.O.C.*)

---

[1] The British Oxygen Co. Ltd., London. (See also B.S.S. 693.)

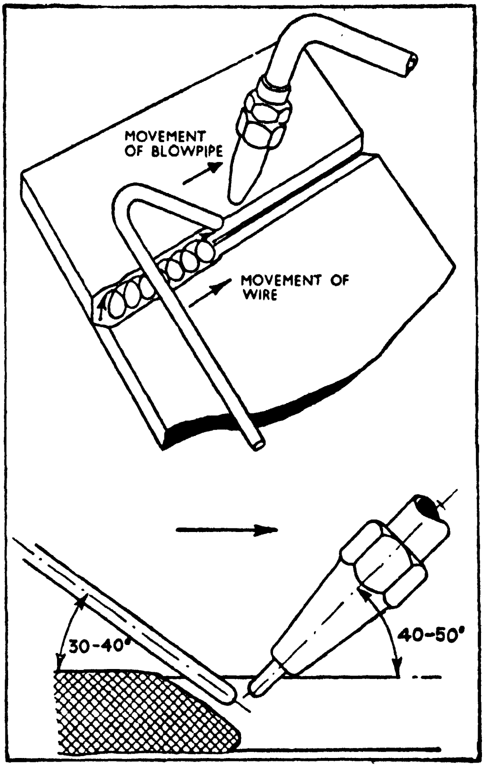


Fig. 2.10. Rightward Welding (*B.O.C.*)

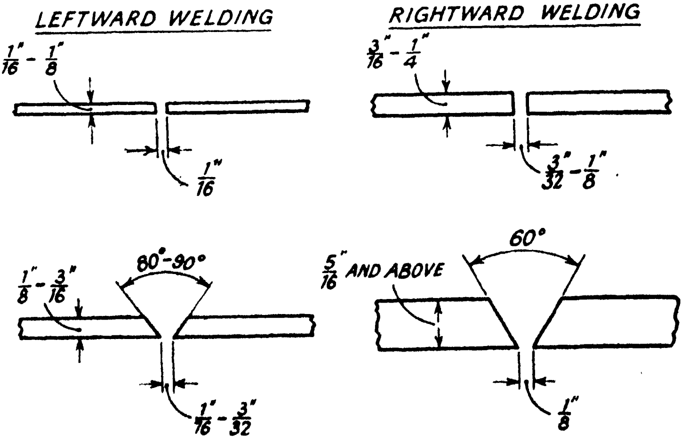


Fig. 2.11

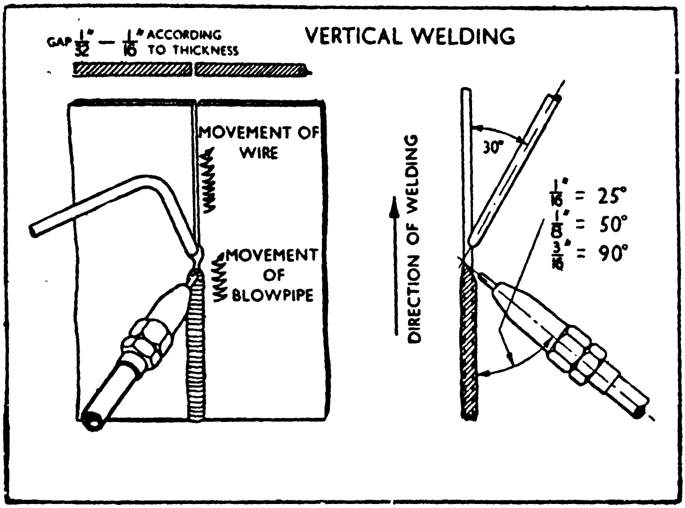


Fig. 2.12. Vertical Welding (*B.O.C.*)

For plate thicknesses of $\frac{3}{16}''$ and above vertical welding by one or two operators is often advantageous, if the plates can be arranged in the required position. It does not require plate edge preparation even for thicknesses up to $\frac{5}{8}''$, and the amount of filler rod material is, therefore, smaller than with horizontal welding. The operator starts at the bottom of the welded joint, and gives an oscillating movement to the blowpipe which points slightly upwards and is preceded by the filler rod with a similar movement (Fig. 2.12). When welding thicker plates by the two operator method (Fig. 2.13), equal heating of both

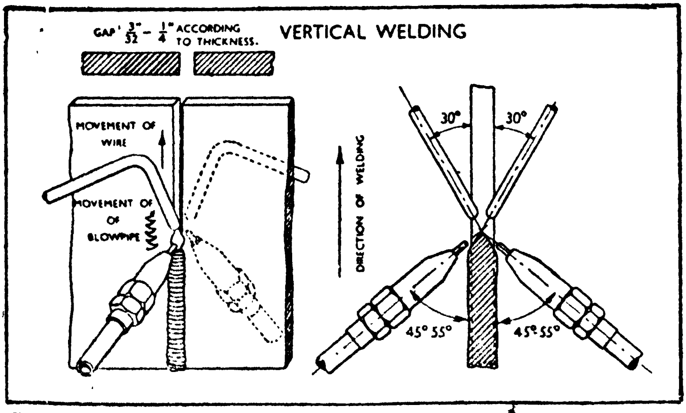


Fig. 2.13. Welding thick plates by two operators, one on each side (*B.O.C.*)

sides of the plates results in less distortions (see page 232), but good timing and co-ordination are essential.

Gas consumption. Tables 3, 4, and 5 give the gas consumption, plate edge preparation, filler rod sizes required, welding speeds, etc., for leftward, rightward, and vertical welding.

TABLE 3

Welding Speeds and Data for Leftward Welding (Steel)[1]

Thickness of plate (inches)	Power of blowpipe cu. ft. acet./hr.	Dia. of filler rod (inches)	Rate of welding ft./hr.	Distance between edges (inches)	Filler rod used per ft. of weld ft. (total)	Preparation of edges
$\frac{1}{32}$	1–2	$\frac{1}{32}$	20–25	—	1·0	Square edges
$\frac{1}{16}$	2–3	$\frac{1}{16}$	25–30	—	1·75	
$\frac{3}{32}$	3–5	$\frac{3}{32}$	20–25	$\frac{1}{16}$	2·75	
$\frac{1}{8}$	5–7	$\frac{3}{32}$	18–20	$\frac{1}{16}$	1·65	
$\frac{5}{32}$	7–10	$\frac{1}{8}$	15–18	$\frac{1}{16}$	2·1	80° to 90° vee
$\frac{3}{16}$	10–13	$\frac{1}{8}$	12–15	$\frac{3}{32}$	4·8	

[1] British Oxygen Co., Ltd.

TABLE 4

Welding Speeds and Data for Rightward Welding (Steel)[1]

Thickness of plate (inches)	Power of blowpipe cu. ft. acet./hr.	Dia. of filler rod (inches)	Rate of welding ft./hr.	Distance between edges (inches)	Filler rod used per ft of weld ft. (total)	Preparation of edges
$\frac{3}{16}$	13–18	$\frac{3}{32}$	12–15	$\frac{3}{32}$	3·4	No vee
$\frac{1}{4}$	18–25	$\frac{1}{8}$	10–12	$\frac{1}{8}$	3·4	
$\frac{5}{16}$	25–30	$\frac{5}{32}$	7–8	$\frac{5}{32}$	3·4	60° vee
$\frac{3}{8}$	35–45	$\frac{7}{32}$	6–7	$\frac{1}{8}$	4·0	
$\frac{1}{2}$	45–50	$\frac{1}{4}$	4.5–5	$\frac{1}{8}$	4·75	
$\frac{5}{8}$	55–60	$\frac{1}{4}$	3.75–4.25	$\frac{1}{8}$	6·75	
$\frac{3}{4}$	60–70	$\frac{1}{4}$	3–3.25	$\frac{1}{8}$	9·75	
1	70–90	$\frac{1}{4}$	2–2.25	$\frac{1}{8}$	16·5	

[1] British Oxygen Co., Ltd.

TABLE 5

Welding Speeds and Data for Vertical Welding (Steel)[1]

Thickness of plate (inches)	Power of blowpipe cu. ft. acet./hr.	Nozzle size for single and double operator	Dia. of filler rod (inches)	Rate of welding ft./hr.	Distance between edges (inches)	Filler rod used per ft. of weld ft. (total)	No. of operators
$\frac{3}{16}$	7·5–8·5	10	$\frac{3}{32}$	7	$\frac{1}{16}$	3·75	1
$\frac{3}{16}$	2·0–3·0	3	$\frac{1}{16}$	12	$\frac{3}{32}$	7·5	2
$\frac{1}{4}$	3·0–4·0	5	$\frac{3}{32}$	10	$\frac{1}{8}$	6·2	2
$\frac{5}{16}$	5·0	5	$\frac{1}{8}$	$8\frac{1}{2}$	$\frac{5}{32}$	5·3	2
$\frac{3}{8}$	7·0	7	$\frac{5}{32}$	$7\frac{1}{2}$	$\frac{3}{16}$	4·9	2
$\frac{1}{2}$	10·0	10	$\frac{5}{32}$	$6\frac{1}{4}$	$\frac{1}{4}$	7·25	2
$\frac{5}{8}$	15·0	18	$\frac{3}{16}$	6	$\frac{1}{4}$	6·25	2

[1] British Oxygen Co., Ltd.

"Linde" welding. This special process has been developed by the Linde Air Products Company in the U.S.A. especially for the butt welding of mild steel pipe. It is based on the fact, that the melting point of steel decreases with an increase in carbon content. By using a carburizing flame (excess acetylene), the heated parent material picks up carbon and melts faster than it would do in its original state. Thus increased welding speed is obtained, and by using silicon manganese filler rods, efficient joints are obtained at reduced cost. The welding flame should be adjusted so as to obtain an acetylene "feather" (Fig. 2.5A) which, measured from the blowpipe nozzle, is twice or two and half times as long as the normal, neutral, cone.

ELECTRIC-ARC WELDING

The arc utilized in electric-arc welding is a low voltage, high current discharge which depends for its maintenance upon the thermionic emission of electrons from the cathode. When the parent plate material is used as one arc terminal, the electrical system (either D.C. or A.C.) is first short-circuited by touching the electrode upon the parent plate, giving rise to a controlled maximum current, which heats the junction of electrode and plate to a temperature sufficient to produce thermionic emission. The electrode is then withdrawn from the plate and the potential difference between the electrode and plate causes electrical breakdown in the now ionized air gap, and the phenomenon of "arcing" occurs. Temperatures are well above 3000°C., the higher temperature—in the case of direct current—being found at the positive pole.

The magnetic forces created by the electric current tend to draw the arc from its shortest line of action and make the arc flame flutter. This is known as "arc blow" and mainly occurs in the D.C. arc, because in the A.C. arc each magnetic force is immediately followed by one in the opposite direction, the arc deflecting influence thus being automatically cancelled. The larger the electrode, the higher the current value, and the longer the arc, the greater will be the effect of arc blow. A short low current arc is, therefore, more stable than a long high current arc.

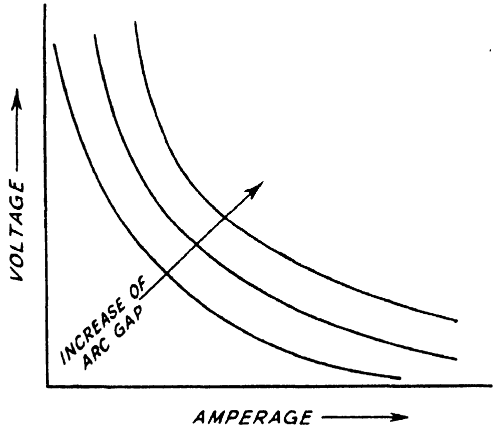


Fig. 2.14

If the arc becomes overloaded due to excessive current rise, a small increase in current causes a rapid voltage drop, and the arc becomes unstable, a condition indicated by a hissing noise.

The longer the arc, the more heat is lost to the atmosphere and therefore from the welding. On the other hand the shorter the arc the greater the possibility of its failure due to short circuits. As a guide, the arc length should be approximately equal to the diameter of the electrode core wire.

The voltage needed to strike the arc is higher than the "arc voltage" needed to maintain it, while the current-flow grows as the voltage decreases after the arc has been established. In each particular arc a definite relation exists between voltage drop across the arc gap and current strength, and the curve showing this relation is called the *characteristic* of the arc (Fig. 2.14).

As the voltage drop depends upon the electric resistance of the arc-gap, the arc characteristic is mainly influenced by the arc length (the arc-gap) and by the chemical composition of the gas surrounding the arc.

When the arc is struck by touching electrode and parent metal, or if—in the case of metal-arc welding—small globules of molten metal bridge an existing arc-gap, a short circuit is created. The short circuit current must be limited, not only in order to protect welding machine and equipment, but also in order to avoid the fusing together of metal electrodes and parent metal. This can be achieved by such an electrical characteristic of the supply plant that the voltage drops rapidly below the welding voltage (necessary to maintain the arc) immediately the maximum permissible short circuit current is reached.

After the arc is struck, i.e. after the electrode is withdrawn to a distance corresponding to the correct arc length, the voltage must rise again to the correct arc voltage.

Arc welding equipment. This comprises essentially, (*a*) electric plant for producing and controlling the arc, and auxiliary plant where necessary, (*b*) electrode holders and electrodes, (*c*) filler material, if required.

Standard *welding generators* or *welding transformers* are employed for most electric-arc welding processes (except the automatic arc and the atomic hydrogen, which demand more specialized plant). They provide for all cases within their specified capacity range, both the necessary voltage for striking an arc and the high welding currents required for the use of large size welding electrodes.

Arc voltage. The open circuit voltage, although high enough for striking an arc, must not be such as to be dangerous to the operator if he touches the electrodes. B.S.S. 638 limits it to a maximum of 100 volts, except for certain rare cases, where special precautions have to be taken to protect the operator. In most cases the open circuit voltage for drooping characteristic generators need not exceed 80 volts. When using A.C. transformers, the maximum open circuit voltage of 100 volts (R.M.S.), is advantageous for certain welding conditions, e.g. vertical and overhead welding, welding of some alloy steels, and carbon-arc welding. Arc voltages usually vary between 25 and 45 volts, according to type and coating of the electrode. Some coatings are designed to give higher arc voltages for special purposes, e.g. deep penetration welding (see tables 8, 9, 10 and also: B. W. Silverwood, *New Developments in Technique of Deep Penetration Welding,* and D. M. Kerr, *Deep Penetration Welding on Plates over 0·350 in. Thick,* Transactions of the Institute of Welding, August 1945.) Correct current control and a current-voltage relation in accordance with the requirements of the arc are essential for obtaining the most favourable welding conditions. Variable current settings and welding machines with a drooping characteristic fulfil these conditions.

D.C. and A.C. compared. Both direct current and alternating current are used for electric-arc welding, each having its particular applications; in some cases, either is suitable. With direct current the greater heat is generated at the positive pole of the arc, and in metal-arc welding, it has been general practice to connect the work to the positive pole of the D.C. generator, and the filler rod to the negative pole, in order to melt the greater mass of metal in the base material. In American welding practice this is called welding with straight polarity. On the other hand, certain types of modern electrodes, due to their coating and material properties, are connected advantageously to the positive pole of the generator (known as welding with reversed polarity).

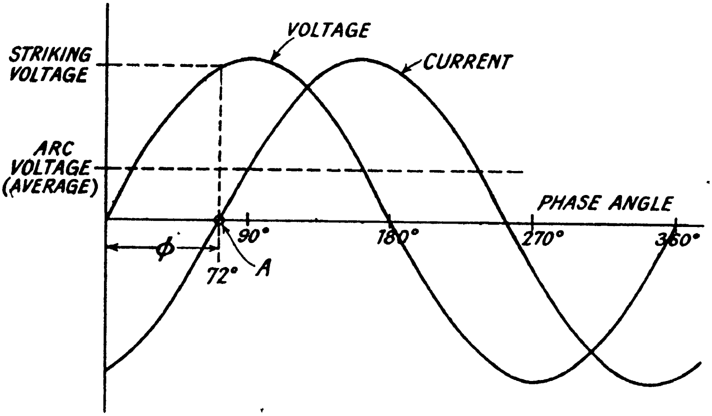


Fig. 2.15

Whilst direct current has, thus, the advantage of allowing a desired heat distribution in the arc, alternating current welding is at present gaining considerable ground, due especially to cost factors, to the flexibility as regards multi-operator sets and to absence of arc blow.

Advantages of A.C. welding may be summarized as follows:

(*a*) As current supply in factories is mostly A.C., a rotating generator is required for D.C. welding, whilst A.C. welding requires only a transformer, the initial cost of which is lower.

(*b*) Maintenance of an A.C. transformer, as there are no moving parts, is less difficult and expensive than that of a D.C. generator.

(*c*) Running costs of A.C. are lower than those of D.C. equipment.

Disadvantages of A.C.

(*a*) There are certain welding conditions, types of parent metal, types of electrodes, for which A.C. is definitely not suitable (see page 120).

(*b*) A.C. equipment has to allow for the fact, that voltage and current values pass through a zero, twice during every cycle. When the current is zero, the voltage value must not be less than the arc-striking voltage required to re-establish the arc. To ensure this, the angle of lag (ϕ) of the current must be about 72° as shown at A in Fig. 2.15. The resultant power factor ($\cos \phi$) is approximately 0·3, a rather low value.

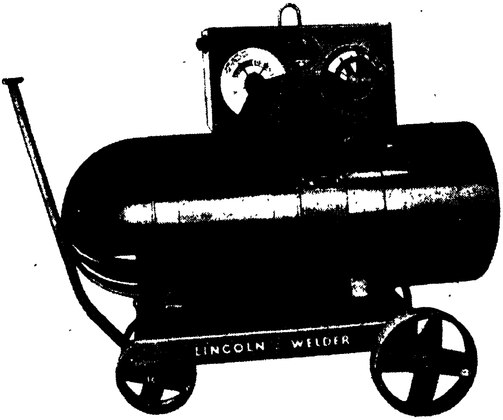


Fig. 2.16. D.C. Welding Generator. Left-hand dial: Voltage control (resistance *c*, Fig. 8.4); Right-hand dial: Current control (resistance *g*, Fig. 8.4) (*Lincoln Electric*)

Welding generators. D.C. welding supply is usually obtained from generators driven by electric motors or—if no electricity is available—by internal combustion engines. The drooping characteristic is obtained by using compound winding in which the series and shunt windings are suitably arranged (see page 146). The welding generator (Fig. 2.16) has a separate exciter and dual rotary hand controls (see page 148) for separate voltage and amperage fine adjustments, so as to obtain a characteristic of the machine to suit any required conditions.

Another type of welding generator (Fig. 2.17) provides finely adjustable voltage control by means of a handwheel, and tappings for three current settings (see page 152).

The above generators are all designed for use by a single operator at a time. In providing generators for multi-operator use, the obvious difficulty lies in the voltage drop which occurs immediately one welder strikes the arc, and which does not give the other welders the open circuit voltage they require. The solution is a compound wound generator which gives practically constant voltage over its whole current range[1]. The drooping characteristic at the arc itself is obtained by means of separate series resistances for each welder. This has the disadvantage of wasting part of the generated electric energy by transforming it into useless heat in the resistance (see page 147).

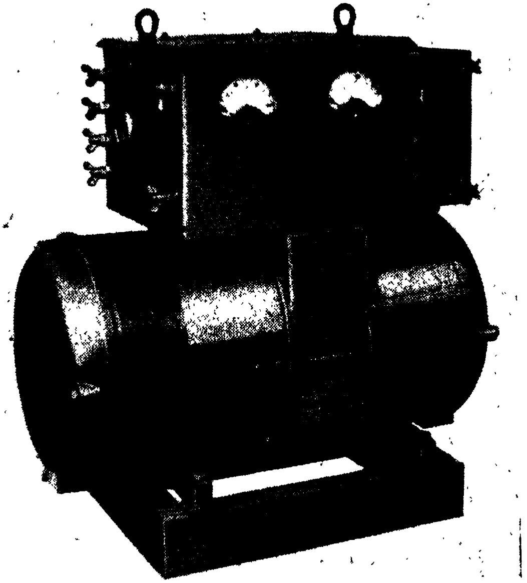


Fig. 2.17. D.C. Welding Generator (*Murex*)

Transformers. For A.C. welding supply, transformers are almost exclusively used. They have to step down the usual supply voltage of 200–440 volts to the normal open circuit welding voltage of 80–100 volts.

In the portable single phase one operator transformer (Fig. 2.18) three ranges of secondary current values can be obtained by tapping,

---

[1] See Murex, *Electric-Arc Welding Manual.*

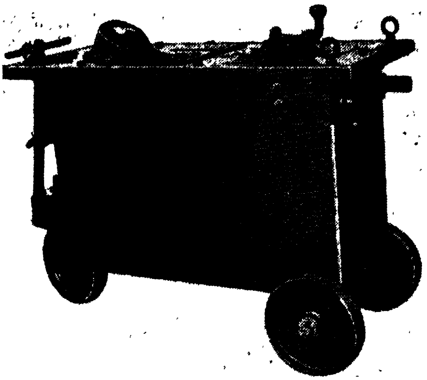


Fig. 2.18. Portable A.C. Welding Transformer (*Murex*)

through a rotary-handle controlled selector switch, the reactance in the transformer circuit (see page 155).

Another method of current adjustment is used in the transformer (Fig. 2.19), where the welding current is varied by sliding an iron core in or out of the reactance in the transformer circuit, thus altering the effective amount of iron remaining in the coil.

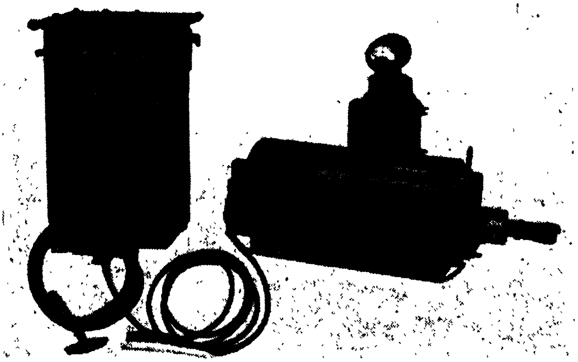


Fig. 2.19. A.C. Welding Transformer (*Murex*)

In case of three phase supply, difficulties are encountered if single phases are tapped for use with each welding transformer, as, even with three welders working, unbalanced loading occurs; because they seldom work simultaneously. Due to this fact, the use of 3 : 1 phase single operator transformer sets is declining considerably, and single phase transformers are now installed nearly exclusively.

The best solution of the problem is probably found in the use of three operator welding transformer sets (see page 157), where each welder has his electrode holder connected to its own reactance coil for current regulation, and uses it as if he were working with a single operator set (Fig. 2.20).

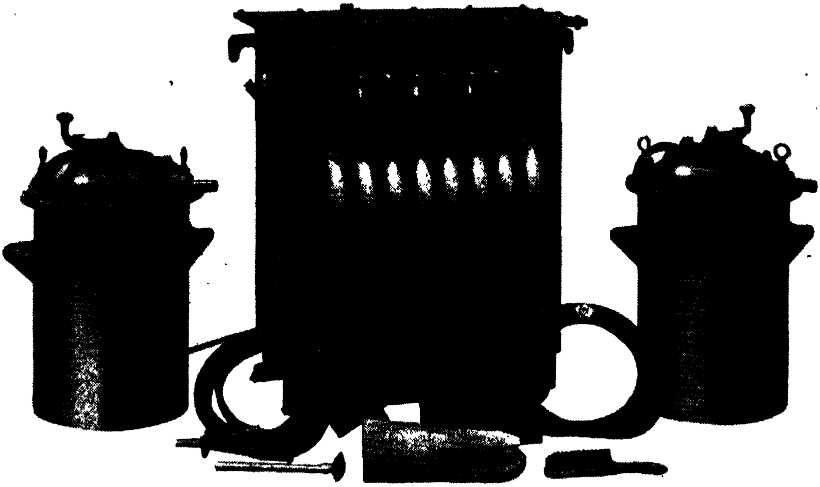


Fig. 2.20. Three Operator A.C. Welding Transformer showing two of the three separate reactance coils (*Murex*)

Whilst the above current supply plant can be used for most electric-arc welding methods, the electrode holders, electrodes, and filler rods, and the whole welding technique are different for the various processes which will now be examined.

CARBON-ARC WELDING[1]

In this method, after the arc is struck either between the carbon electrode and the parent material or between two carbon electrodes (twin carbon-arc welding), material from the filler rod is fed into the molten pool of the parent material as in oxy-acetylene welding, but flux has generally to be used to create a protective atmosphere which prevents contamination of the weld metal. When using D.C. for single carbon-arc welding it is recommended to connect the carbon electrode to the negative pole of the generator, as a more stable arc is obtained and the weld metal will pick up less carbon from the electrode. A solenoid is often incorporated in the carbon-electrode holder in order to stabilize the arc, particularly in the case of small size electrodes up to ¼″ diameter, the solenoid coil lying around the carbon electrode. If the arc is drawn between two carbon electrodes, a solenoid in the electrode holder directs the arc against the welding point (Fig. 2.21).

---

[1] See P. L. Pocock, "Carbon-Arc Welding," *Welding*, February, March, May, 1945.

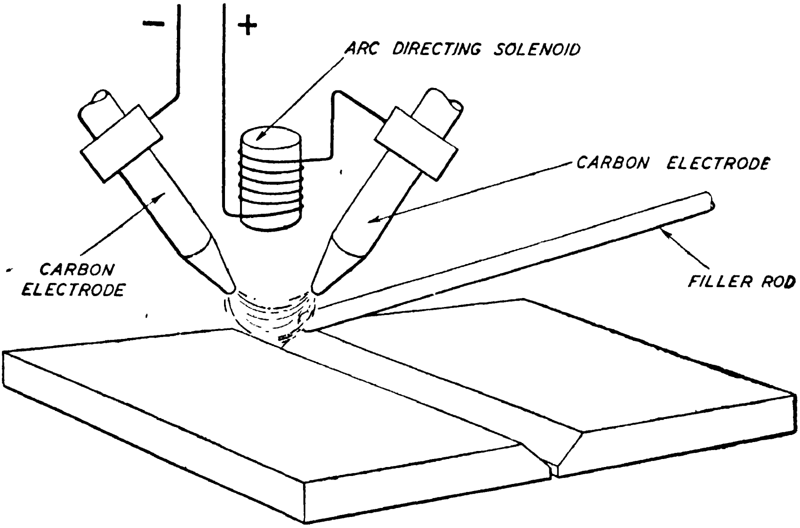


Fig. 2.21

When using A.C. for single carbon-arc welding, 100 volts open circuit voltage is essential. Whilst A.C. cannot be used for welding materials on which carbon pick-up has to be completely avoided, it is advantageous for twin carbon-arc welding, as it ensures equal electrode consumption at both ends of the arc.

Automatic carbon-arc welding equipment has been developed[1], in which the arc length is automatically maintained through feeding the carbon against the parent material. Flux is automatically supplied, unless previously applied in paste form. The filler material, if required, is either laid along the intended welded seam before the operation commences, or fed into the arc from a coil mounted on a rotating drum.

[1] See P. L. Pocock, loc. cit.

ARGON-ARC WELDING

In argon-arc welding the electric arc is struck between a tungsten electrode and the parent material, and is surrounded by an argon gas shield which protects the molten metal from chemical action of atmospheric elements. The equipment used is diagrammatically shown in Fig. 2.22.

Argon (chemical symbol " A ", weight ·113 lb. per cubic foot), an odourless inert gas obtained from liquid air by fractional distillation, is stored in steel cylinders, painted blue for identification, at a pressure of 120 atmospheres. The gas pressure required for the actual welding varies from 2 to 10 lb. per square inch according to the welding job (see pages 111 and 126), and can be adjusted by means of a pressure-reducing regulator.

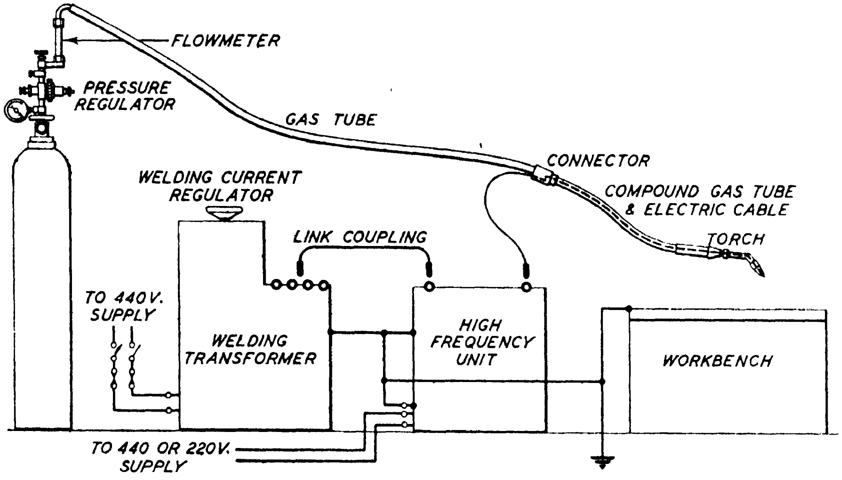


Fig. 2.22 (*B.O.C.*)

Electric power supply can be from generators (D.C.) or transformers (A.C.). With 50-cycle A.C. difficulties would be encountered in striking and maintaining the arc, as the current is reversed 100 times per second, and every 1/100 second no current flows, and restriking of the arc becomes necessary. Whilst the usual open-circuit voltage of 100 volts, is sufficient when using coated electrodes (see page 39), it is rather low for striking and maintaining the arc with a bare wire, such as the tungsten electrode. Although the argon shield may give certain protection to the arc, its conductivity alone is not sufficient for this purpose.

To overcome this difficulty, an electronic unit has been developed, in which a high frequency oscillator provides a high voltage low current supply. This is connected at one end to the electrode, at the other to the parent material (see Fig. 2.22). When the main welding current and the high frequency current are switched on, and the electrode is brought within about $\frac{3}{16}''$ from the parent material to be welded, a high voltage high frequency discharge across the gap (Fig. 2.23) forms an ionized path in the argon gas which is leaving the torch nozzle. This provides the conductor through which the main current (low voltage, high amperage) will flow as an arc, without actual contact being made between electrode and parent material. The high frequency supply is maintained during the whole welding period, and each time the main current value goes through zero, it restrikes and thus maintains the arc. The high frequency current is very low, so that in spite of the high voltage there is no danger for the operator; but to avoid even minor shocks which might be transmitted through the filler rod, light gloves of insulating material are usually worn.

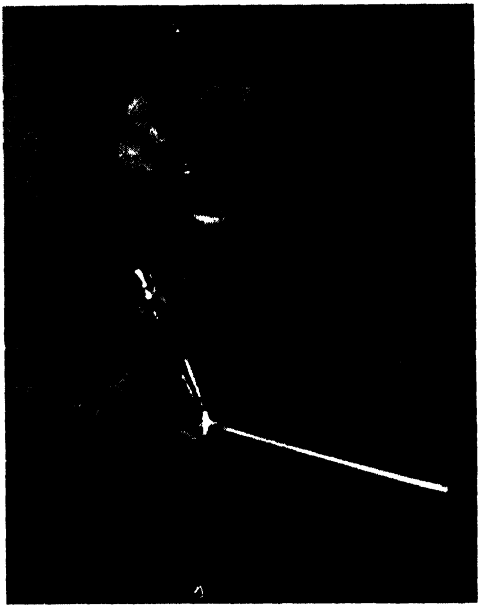


Fig. 2.23. High Frequency Discharge for starting Argon-Arc Welding (*B.O.C.*)

Although, when using D.C., the high frequency unit is not essential, it facilitates striking of the arc, especially in less accessible places, where the high frequency spark can be started at a distance which is still too long for the main welding arc to go across. By exactly positioning it before shortening the distance, the main arc can be started at exactly the spot required, without damaging any adjacent material.

The current-supply cable and the gas tube are both connected to the handle end of the welding torch (Fig. 2.24) which carries the electrode holder and the gas nozzle. Interchangeable torch heads can be connected, as can tungsten electrodes of different sizes, which are gripped in collets of heat resistant steel. These collets are held in position by rings made from a material of a very low coefficient of expansion, so as to avoid loosening of the collet grip under the heat. The nozzle-shaped hood is screwed over the electrode holder.

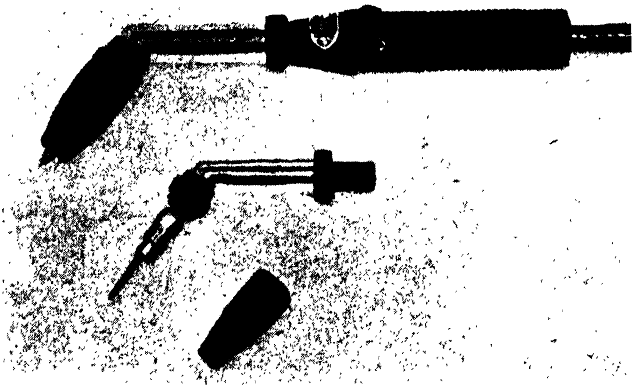


Fig. 2.24. Argon-Arc Welding Torch, Electrode Holder and Gas Nozzle (*B.O.C.*)

The electrodes of tungsten (melting point 3350°C.) do not melt in the arc although a slight loss may occur in time, depending on the electrode size and the current used, both of which factors have to be varied according to the type and size of material.

Although greater heat is generated at the positive end of the arc, and is usually required at the parent metal, it is recommended—in the case of manual welding—to connect the electrode to the positive pole of the generator. It has been observed that a smooth finish can thus be obtained and manipulation is easier than it would be otherwise, when the variation in arc length, which is unavoidable in manual welding, would cause difficulties.

The current which can be used for manual welding is limited, as overheating of the torch head may occur due to the greater heat development at the positive pole. But with automatic welding equipment which maintains the arc length constant, high-speed, heavy-current welding can be carried out. The electrode is in this case connected to the negative pole, and the greater heat is, in this case, created in the parent material.

The manual welding technique is similar to that used in oxy-acetylene welding. The operator holds the torch in his right hand, the electrode being inclined at an angle of about 80° from the horizontal and in line with the edges to be welded. With his left hand he holds the filler rod and feeds the melting end into the molten pool of parent metal as he goes along. With plates above ⅛″ thickness with chamfered edges a slight weaving motion of torch and filler rod may prove advantageous.

Current and gas pressure settings, sizes of electrodes and filler rods are discussed in the chapters dealing with the welding of stainless steels and light alloys.

METAL-ARC WELDING

The arc in this process is drawn between the parent material and the filler rod which constitutes the electrode, so that metal at both ends of it, parent material and filler rod, is melting under the heat of the arc, and the molten particles of the electrode are deposited in the molten pool of parent material. Whilst some of the molten electrode material is dropping, due to gravity action, into the molten pool of the parent material, other particles are propelled in the arc stream towards it. One pole of the standard generator or transformer (see pages 29–30) is connected to the parent material (earth) the other to the electrode holder. The operator holds the latter with his right hand and, after having struck the arc, guides the electrode at the correct distance (the arc length) along the edges to be welded. As the filler rod shortens, the electrode holder has to come nearer the parent material, and it is part of the skill of the welder to keep the arc length as constant as possible.

Since electrode material is consumed as welding proceeds, electrode holders must not only clamp the electrode firmly but also allow replacement in the shortest possible time; furthermore, good electrical contact between clamping device and electrode end must be provided. The electrode holder must be light, handy and well-balanced so as to cause minimum fatigue to the operator. The handle must be well-insulated, and the connecting cable to the power supply must be amply dimensioned to prevent undue heating. Fig. 2.25 shows a typical electrode holder. The drawback encountered in most electrode holders arises from the clamping spring being weakened after a certain time, through the heat at the clamping point. This occurs particularly in case of welding with large size electrodes and consequently heavy currents, where weight considerations force the electrode designer to use a weaker clamp than desirable. Developments are—of course—constantly going on in this field.

Electrodes. These require particular consideration, as they combine the functions of arcing electrode and of filler rod. So far as the latter is concerned their composition depends on the parent material as in other processes. Originally, bare wire electrodes were generally used. When working with D.C., the electrode was attached to the negative, and the parent material to the positive pole of the supply where, with D.C., the heat is greatest. Heat dissipation is greater in the large plate than in the relatively thin electrode wire, and more metal has to be in a molten state in the parent material than in the electrode.

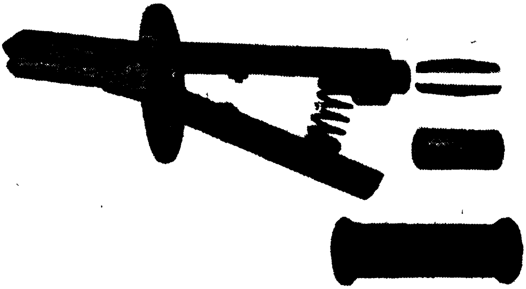


Fig. 2.25. Metal-Arc Welding Electrode Holder
(*Murex*)

Various problems are, however, encountered when using bare electrodes. Whilst it is not too difficult to start and maintain a D.C. arc with a bare electrode, difficulties are encountered when using A.C. The time during which the voltage is off (100 times per second) usually allows the electrode tip and the parent material to cool down sufficiently to make a restriking of the arc impossible when the voltage comes on again. Moreover, at the high temperature which exists in the molten metal, the affinity of the material to foreign elements is increased, and there is a danger of impurities entering either the molten particles travelling between electrode and parent material, or the molten pool during the solidifying period. If, furthermore, a certain depth of penetration is required, too rapid melting of the electrode would not give the parent material sufficient time to melt to any depth.

Coated electrodes. To overcome the above difficulties and to improve the quality of the weld, covered electrodes are now almost exclusively used in metal-arc welding. The coating generally melts at a slightly higher temperature than the metal core. It extends, therefore, a little beyond the latter (Fig. 2.26) and directs the arc, also preventing sideways arcing when welding in deep grooves. Some coatings also form a protective non-oxidizing or reducing gas shield around the arc, thus protecting the globules of molten metal travelling through the arc.

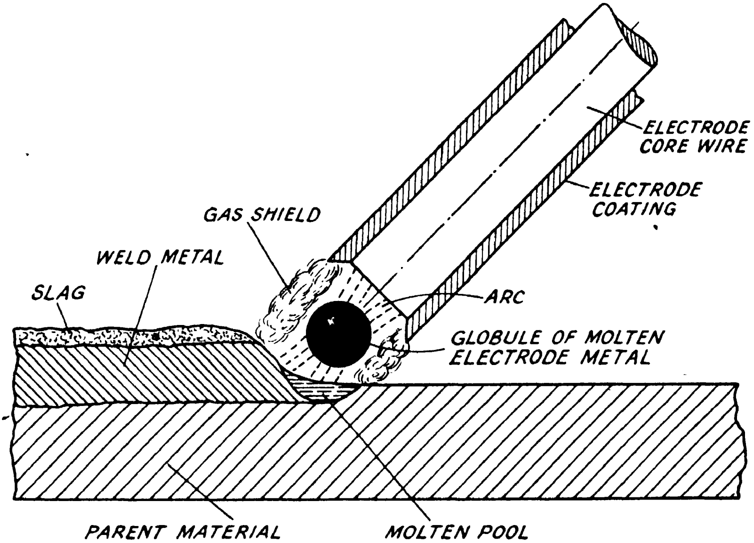


Fig. 2.26

The gas formed by the coating usually emits electrons sufficient to re-ignite and therefore maintain the A.C. arc whenever it is extinguished due to the zero point of the amperage. The gas shield round the arc also reduces heat losses and counteracts rapid cooling and the resulting difficulty in restriking an A.C. arc. The gas solidifies on the weld as slag, and protects the welded seam against contamination during the cooling period. When laying down multi-run welds this slag has to be carefully removed from each layer before the next one is started.

The coating may even contain elements or alloys which are added to the welded seam during the welding process, and improve its composition.

The greater the heat absorption of the coating, the deeper will be the weld penetration, as more time is available for the parent metal to melt before the electrode metal is thrown into the molten pool.

Some coatings absorb so much heat, that reversed polarity welding is necessary, i.e. the electrode is connected to the positive pole of a D.C. supply. In the case of A.C. welding, where the heat is equal at both poles of the supply, the coating is so arranged as to control and secure the correct ratio of heating of electrode metal and parent material. "Deep penetration" welding can thus be made possible, as the melting of the electrode metal can be delayed until the parent metal is molten to the required depth.

The arc voltage is also considerably influenced by the coating. If, for example, hydrogen is contained in the coating, a considerable increase of the arc voltage and the developed arc energy is obtained.[1] Various types of electrodes and coatings are available, and their specific application will be discussed in connection with different types of welds and materials.

In order to distinguish systematically the typical features of the great variety of electrodes on the market, and thus to enable manufacturers and users to judge their applications, a classification of arc welding electrodes has been introduced by a joint committee set up by the Institute of Welding and the British Electrical and Allied Manufacturers' Association (BEAMA).[2] It covers the most generally used electrodes producing weld metal in accordance with B.S.S.639, class "A", a standard which is obtained with the great majority of British electrodes at present available. The classification comprises method of manufacture, type of flux covering, welding position for which the electrode is suitable, recommended current conditions and suitability for deep penetration welding.

Method of manufacture. Symbol "E" indicates that the electrodes are produced by solid extrusion, i.e. the flux coating is applied to the core wire under pressure, resulting in accurate thickness and homogenity of the coating. Symbol "R" indicates a reinforcement of the coating by means of yarn or wire material, making the coating robust and resistant to rough handling. Symbol "D" indicates that the coating has been applied by dipping the wire in a bath of the flux material, a method which is less frequently used to-day, due to the lesser control over homogenity and accuracy of the coating.

---

[1] *Handbook for Electric Welders,* Murex Welding Process Ltd., Waltham Cross, Herts.

[2] See *Transactions of the Institute of Welding,* April 1947. A critical survey of this classification is given in "Choose the Right Electrode," by W. D. Waller, *Welding,* August, October, November, 1947.

Type of flux covering. Six classes (1 to 6) have been established. These vary in their composition, producing different types of gas shields during welding and different types of slag covering the deposited weld metal. The type of flux affects depth of penetration, ease of maintaining the arc and of welding in different positions, limitation of weld spatter, and quality of the weld metal itself (see above).

Weld position (see page 46). In accordance with the above-mentioned influence of the flux material, electrodes are classified according to their suitability for flat (downhand) position welding (Class " F "), inclined position (Class " I "), horizontal-vertical position (Class " H "), vertical position (Class " V "), and overhead position (Class " O ").

The following code numbers indicate the suitability for various weld positions:

Code No.	Suitable for position
1.	F.I.H.V.O.
2.	F.H.
3.	F.
4.	F.I.H.
5.	F.H.V.O.
6.	V.O.
9.	Not classified

Current conditions. The suitability in use with D.C. or A.C., and the recommended polarity is indicated by

Class D+	, D.C.	Electrode connected to the positive pole of the generator.
Class D−	, D.C.	Electrode connected to the negative pole of the generator.
Class D±	, D.C.	Usable with either polarity.
Class A	, A.C.	Open circuit voltage not less than 95 volts.
Class a	, A.C.	Open circuit voltage not less than 70 volts.
Class a*	, A.C.	Open circuit voltage not less than 45 volts.

The following code numbers indicate the recommended current conditions:

Code No.	Current condition
0.	D+
1.	D+ A
2.	D- a
3.	D- a*
4.	D+ a
5.	D± A
6.	D± a
7.	D± a*
9.	Not classified

Deep penetration welding. The letter " P " indicates that the electrode will produce satisfactory deep penetration welds.

As an example, an electrode marked " E.135.P. " will be of the extruded type (E), flux class 1 (1), suitable for welding in the flat position only (3), to be used with D.C. with either polarity and with A.C. with an open circuit voltage of not less than 95 volts (5), and will produce satisfactory deep penetration welds (P).

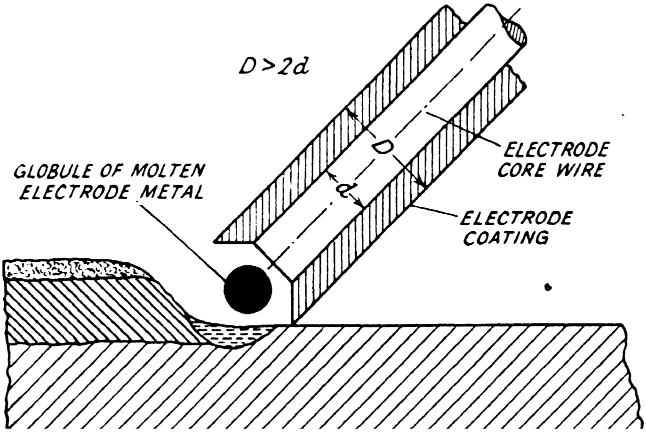


Fig. 2.27

A new type of electrode has been developed recently and has introduced a new method called "Contact Arc Welding".[1] With normal electrodes the welder has to keep the arc length constant by moving the electrode holder steadily towards the parent material, at the rate at which the electrode core shortens. The coating of the electrodes for contact arc welding is thick enough to prevent the globules of molten metal, which travel in the arc from the electrode to the parent material, from touching at the same time the solid electrode core wire and the parent material, even if the coating itself touches the parent plate (Fig. 2.27). The welder can, therefore, rest the electrode coating on the parent material during the welding operations, without the danger of the arc being short-circuited by the globules of molten metal travelling through it.

A further feature of these electrodes is the fact that part of the weld metal, as contained in the core wire, is also contained in a finely divided form in the coating, so that in the final weld, the ratio of metal to slag is equal to that obtained with ordinary welding electrodes. The slight conductivity of the coating also enables the welder to strike the arc by touching the parent material with the coating, and, once the arc is struck, welding is carried out by sliding the electrode along the plate to be welded, at an angle of about 45°.

Preparation for arc welding. Recommended plate edge preparations for arc-welded butt joints are specified in B.S.S.538 (Fig. 2.28). The chamfered V-preparation, when applied to thicker plates, requires a large angle α (see Fig. 2.28) in order to enable the welder to get right down to the root of the weld with the electrode for his first run. A large angle α, however, means a great amount of weld metal to fill the gap, and is, therefore, uneconomical. For such cases, U- or J- preparations are recommended, which combine good accessibility at the root with economical width at the top of the weld. For large plate thicknesses, double V-, double U-, or double J- preparations may be used, which not only show a saving in weld metal as compared with single-sided preparation, but also provide an opportunity of welding simultaneously from both sides, thus ensuring an equal application of heat to both faces of the structure and decreasing distortion (see page 23).

When building up butt welds of thicker plates (Fig. 2.7) or large size fillet welds (Fig. 2.8) by a number of layers, the weld metal required can be deposited either with a large number of smaller runs (by using smaller size electrodes), or with a small number of large runs (by using large size electrodes). The main advantage of the former method is the grain refinement and consequent increase of impact

---

[1] P. C. Van Der Willigen, "Contact Arc Welding," Welding Research Supplement, *Welding Journal*, May 1946.

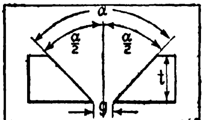
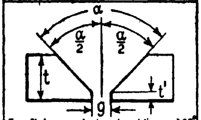
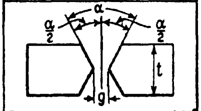
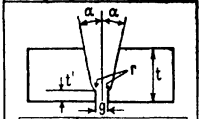
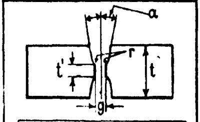
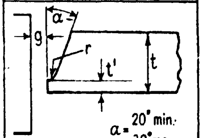
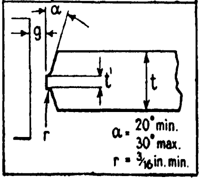
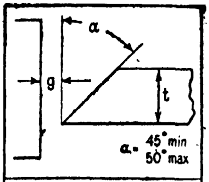
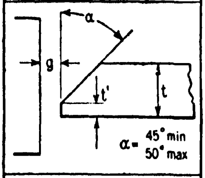
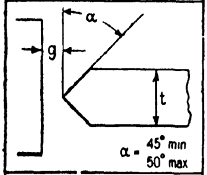
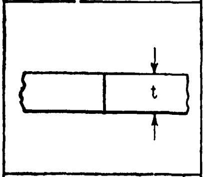
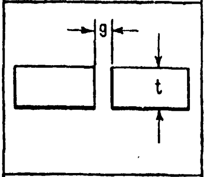
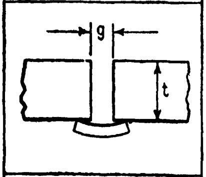
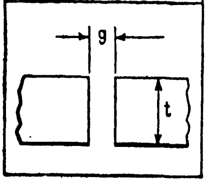
Type	*Detail of weld*	*Plate thickness* t in.	*Root face* t′ in.	*Gap* g in.
Single V	 For flat or underhand welding ··α ≮ 60° For vertical & upright horizontal welding···α ≮ 70° For overhead welding···α ≮ 80°	Not more than ⅜ Over ⅜	— —	1/16 min., 3/16 max. ⅛ min., ¼ max.
Single V	 For flat or underhand welding ··α ≮ 60° For vertical & upright horizontal welding···α ≮ 70° For overhead welding ·α ≮ 80°	Not more than ⅜ Over ⅜	1/16 max. ⅛ max.	1/16 min., 3/16 max. ⅛ min., ¼ max.
Double V	 For flat or underhand welding··α ≮ 60° For vertical & upright horizontal welding ·α ≮ 70° For overhead welding··α ≮ 80°	Not more than ⅜ Over ⅜	— —	1/16 min., 3/16 max. ⅛ min., ¼ max.
Single U	 r = ⅛ in α = 15° min r = 3/16 in or more α = 10° min.	Not more than ½ Over ½	1/16 max. ⅛ max.	⅛ min., ¼ max. ⅛ min., ¼ max.
Double U	 r = ⅛ in. α = 15° min r = 3/16 in or more α = 10° min	Not more than ½ Over ½	1/16 max. ⅛ max.	⅛ min., ¼ max. ⅛ min., ¼ max.
Single J	 α = 20° min. 30° max. r = 3/16 in min.	Not more than ½ Over ½	1/16 max. ⅛ max.	⅛ min., ¼ max. ⅛ min., ¼ max.
Double J	 α = 20° min. 30° max. r = 3/16 in. min.	Not more than ½ Over ½	1/16 max. 1/16 max.	⅛ min., ¼ max. ⅛ min., ¼ max.

Fig. 2.28. Plate Edge Preparations for Butt Welds (Extracted from
28 Victoria Street, London, S.W.1, from whom official copies of

Type	*Detail of weld*	*Plate thickness* t in.	*Root face* t′ in.	*Gap* g in.
Single bevel		Not more than $\frac{3}{8}$ Over $\frac{3}{8}$	—	$\frac{1}{8}$ min., $\frac{1}{4}$ max. $\frac{3}{16}$ min., $\frac{5}{16}$ max.
Single bevel		Not more than $\frac{3}{8}$ Over $\frac{3}{8}$	$\frac{1}{16}$ max. $\frac{1}{8}$ max.	$\frac{1}{8}$ min., $\frac{1}{4}$ max. $\frac{3}{16}$ min., $\frac{5}{16}$ max.
Double bevel		Not more than $\frac{3}{8}$ Over $\frac{3}{8}$	Nil Nil	$\frac{1}{8}$ min., $\frac{1}{4}$ max. $\frac{3}{16}$ min., $\frac{5}{16}$ max.
Square butt		Not more than $\frac{1}{8}$	—	0 to $\frac{1}{16}$
Square butt		Not more than $\frac{3}{16}$	—	$\frac{1}{16}$ min., $\frac{1}{8}$ max.
Square butt		Not more than $\frac{1}{2}$	—	1.4 x overall dia. of electrode* for horizontal welding 1.8 x overall dia. of electrode* for vertical welding
Square butt		$\frac{3}{16}$ to $\frac{1}{2}$ for vertical welding only	—	1.2 x overall dia. of electrode* for vertical welding only

* Overall diameter of electrode to be measured over coating

B.S. No. 538 by permission of the British Standards Institution, the specification can be obtained price 2*s*. post free.)

strength obtained in the weld metal, due to the fact that during welding each layer anneals the foregoing one.

On the other hand less distortion and higher welding speeds can be obtained by using large size electrodes and depositing a minimum number of runs per welded joint. Subject to accessibility to the weld root, large size electrodes will, therefore, prove to be more economical. Furthermore, the use of small electrode sizes, particularly for first runs, may result in cracks between the weld and the parent material especially when the area resisting shrinkage is too small (see also page 106). Table 6 gives the minimum fillet weld sizes of first runs in relation to the thickness of the plates to be welded.

TABLE 6

Minimum Sizes of Fillet Welds[1]

Plate thickness (inches)	Minimum fillet weld size (inches)
Up to $\frac{1}{2}$	$\frac{3}{16}$
$\frac{9}{16}$ to $\frac{3}{4}$	$\frac{1}{4}$
$\frac{13}{16}$ to $1\frac{1}{4}$	$\frac{5}{16}$
$1\frac{5}{16}$ to 2	$\frac{3}{8}$
$2\frac{1}{16}$ to 6	$\frac{1}{2}$
Above 6	$\frac{5}{8}$

[1] Building Code and Bridge Code of the American Welding Society.

Four typical welding positions are usually considered (Fig. 2.29). They are the downhand (*a*), the horizontal-vertical (*b*), the vertical (*c*) and the overhead (*d*) position.

The *downhand* position is the most favourable, as far as ease, obtainable profile, and speed are concerned, because gravity helps to give the weld metal even distribution. If possible, it is advisable to " position " welded parts under construction, so as to make downhand welding possible, by using welding-positioners, also called manipulators (see page 205). The *horizontal-vertical* position is slightly less favourable than the downhand position, and difficulties will be encountered when welding in the *vertical* position, as the molten metal may tend to run down instead of staying where it has been deposited. In *overhead* welding the molten globules of weld metal are forced through the arc on to the welding point against the force of gravity. Correct current settings and suitable electrodes are essential for successful overhead welding which is also more fatiguing to the operator than welding in the other positions.

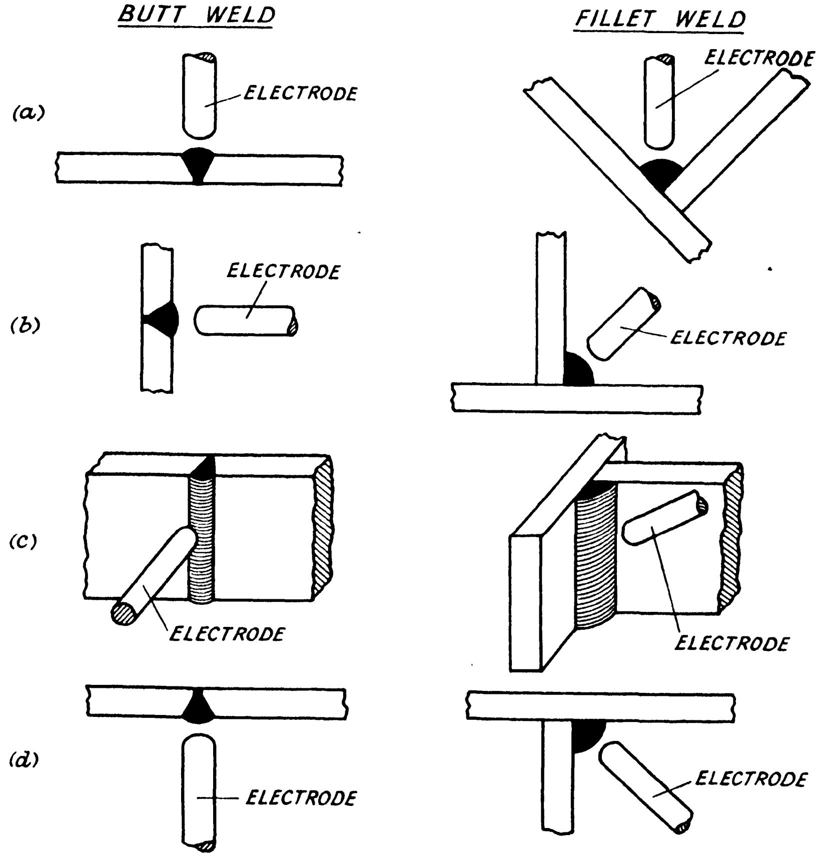


Fig. 2.29

Suitable electrodes and welding machine settings are usually specified by the electrode manufacturers. Typical specifications for various types of welds and welding positions are shown in Tables 7–16 and in Figs. 2.30–2.32.[1]

TABLE 7

Butt Welds in Mild Steel: Downhand[1]

V. Butt, included angle, 60°

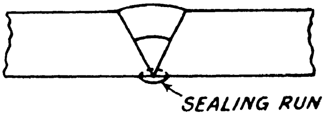


Plate thickness (inches)	Number of runs	Gauge of electrode	Current (amps.)
$\frac{1}{4}$	1	6	220
$\frac{5}{16}$	1	6 4	220 260
$\frac{3}{8}$	1	6 4	260
$\frac{1}{2}$	1 2	6 4	260

It is uneconomical to weld plates of more than $\frac{1}{2}$ inch thickness by the above method.

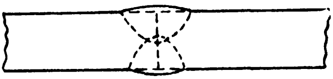
---

[1] In order to give a consistent picture of the different welding conditions, procedure specifications for various cases of metal-arc welding, issued by one electrode manufacturer are shown throughout the book. This does by no means imply any judgment on the quality of this make of electrodes as compared with those produced by many other manufacturers of first class welding equipment.

[1] Murex Welding Processes Ltd.

TABLE 8

Butt Welds in Mild Steel. Downhand. Deep Penetration Method. Unprepared Plates[1]



The cost of bevelling plate edges, and also time, can be saved by adopting the deep penetration method.

This process requires the use of A.C. welding plant of sufficient capacity, and, to obtain the best results, an open circuit voltage of 100.

The welding operation is simple, and as the electrode only requires to be drawn along the seam without side movement, it is less fatiguing to the operator, even when large gauge electrodes are employed.

The plate edges should be clean gas cut or guillotine sheared. It is important that the fitting is good, as gaps will cause the arc to melt through and leave holes.

Table 8 gives data for close butt joints welded by hand on jobs which can be turned over to weld the other side.

Plate thickness (inches)	Size of electrode (inches)	Current (amps.)
$\frac{1}{4}$	$\frac{1}{4}$	325
$\frac{5}{16}$	$\frac{1}{4}$	400
$\frac{3}{8}$	$\frac{1}{4}$	400
$\frac{7}{16}$	$\frac{5}{16}$	460
$\frac{1}{2}$	$\frac{5}{16}$	470
$\frac{5}{8}$	$\frac{5}{16}$	560

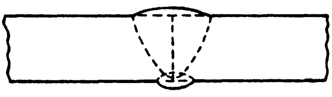
Plates above this thickness cannot be consistently welded to give complete penetration by this method.

---

[1] Murex Welding Processes Ltd.

TABLE 9

Butt Welds in Mild Steel. Downhand. Deep Penetration Method. Unprepared Plates[1]



Butt joints are often required to be made by the deep penetration method in circumstances which prevent the turning of the plate to weld the under side. If a backing strip is undesirable, the joint can be made by first depositing an overhead sealing run on the under side of the seam and then completing the weld from the top side. Deep penetration electrodes should be used.

Plate thickness (inches)	Size of electrode	Current (amps.)
$\frac{1}{4}$	8 S.W.G. $\frac{5}{16}$ in.	130 430
$\frac{5}{16}$	8 S.W.G. $\frac{5}{16}$ in.	130 560

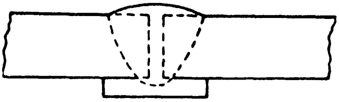
Plates above this thickness will not consistently give full penetration if welded by this method.

---

[1] Murex Welding Processes Ltd.

TABLE 10

Gap Butt Welds in Mild Steel with Back Strap. Deep Penetration Method [1]



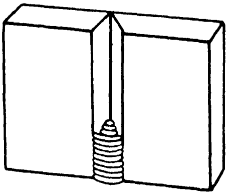
With plate thickness shown in the Table it is possible by leaving a small gap between the plate edges to ensure full penetration into a back strap or stiffener.

Plate thickness (inches)	Gap (inches)	Size of electrode (inches)	Current (amps.)
1/4	1/8–5/32	5/16	450
5/16	1/8–5/32	5/16	560
3/8	1/8–5/32	5/16	560
7/16	3/16	5/16	560 470

[1] Murex Welding Processes Ltd.

TABLE 11

Butt Welds in Mild Steel. Vertical Position—Upwards Direction [1]



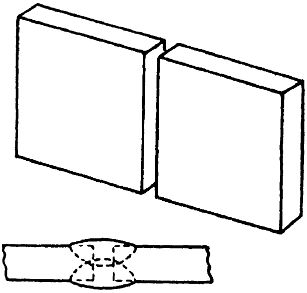
The plates should be bevelled to form an angle of 70° and a gap of 1/16 in. left at the root.

Plate thickness (inches)	No. of runs	Gauge of electrode	Current (amps.)
1/8	2	8 6	125 160
7/16	3	8 6 6	125 160 160
1/2	3	8 6 6	125 160 160

[1] Murex Welding Processes Ltd.

TABLE 12

Butt Welds in Mild Steel. Vertical Position—Upwards Direction. Unprepared Edges[1]



Vertical welds can be made between square-edged plates if the necessary gap is left to ensure complete penetration.

The welds can be made with one run from each side of the plate in the upwards direction.

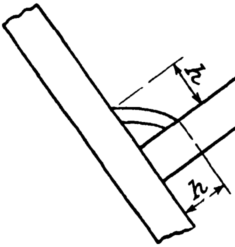
Plate thickness (inches)	Gap (inches)	Gauge of electrode	Current (amps.)
$\frac{3}{16}$	$\frac{1}{16}$	10	95 135
$\frac{1}{4}$	$\frac{1}{16}$	10	115 135
$\frac{5}{16}$	$\frac{1}{8}$	10	115 135
$\frac{3}{8}$	$\frac{5}{32}$	8	135 160
$\frac{1}{2}$	$\frac{3}{16}$	8	135 170

---

[1] Murex Welding Processes Ltd.

TABLE 13

Fillet Welds in Mild Steel. Downhand Position[1]



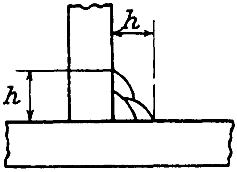
If possible, work should be tilted so that the fillet welds can be made in the downhand position.

Size of fillet "h" (inches)	Gauge of electrode	Number of runs	Current (amps.)
$\frac{1}{8}$	8	1	170
$\frac{3}{16}$	6	1	210
$\frac{1}{4}$	4	1	250
$\frac{5}{16}$	4	1	250
$\frac{3}{8}$	4	1	250
$\frac{1}{2}$	4	3	300

[1] Murex Welding Processes Ltd.

TABLE 14

Fillet Welds in Mild Steel. Horizontal—Vertical[1]



The majority of fillet welding work has to be carried out between two plates, one in the vertical and one in the horizontal position.

For this class of work, an electrode must be employed which will avoid undercut (see page 242) and produce a weld of the correct shape.

Fillet welds above ¼-in. leg length "h" are extremely difficult to make in one run if accurate contour and leg length are to be maintained.

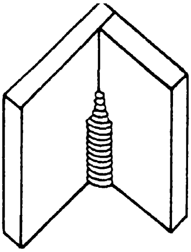
Size of fillet "h" (inches)	Gauge of electrode	Number of runs	Current (amps.)
⅛	8	1	170
3/16	4	1	320
¼	4	1	320
5/16	4	1	320
⅜	4 4 4	3	320
½	4 4 4 4	4	

---

[1] Murex Welding Processes Ltd.

TABLE 15

Fillet Welds in Mild Steel. Vertical Position—Upwards Direction [1]

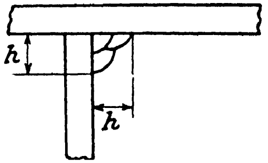


Size of fillet "h" (inches)	Gauge of electrode	Number of runs	Current (amps.)
$\frac{3}{16}$	8	1	160
$\frac{1}{4}$	8	1	160
$\frac{5}{16}$	8 6	2	160 160
$\frac{3}{8}$	6 6	2	160 160
$\frac{1}{2}$	6 6	2	160 160

Murex Welding Processes Ltd.

TABLE 16

Fillet Welds in Mild Steel. Overhead Position[1]



For welds in this position, large beads should be avoided so that the forward travel of the electrode can be rapid with the minimum of side movement.

Large fillet welds are built with up with a series of successive runs in order that the minimum of heat accumulates in the weld near the crater. Following this technique, the weld metal will freeze rapidly and stay in the required position.

Size of fillet " h " (inches)	Gauge of electrode	Number of runs	Current (amps.)
$\frac{3}{16}$	6	1	200
$\frac{1}{4}$	6	2	200
$\frac{5}{16}$	6	3	200
$\frac{3}{8}$	6	3	200
$\frac{7}{16}$	6	6	200
$\frac{1}{2}$	6	6	200

---

[1] Murex Welding Processes Ltd.

Whilst Tables 7–16 and Figs. 2.30–2.32 give a general guidance as to the order of magnitude of current requirements for the various electrode types and sizes employed, the exact value of most favourable current settings for particular welding operations is influenced by the following factors:

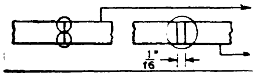
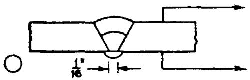
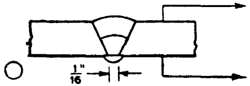
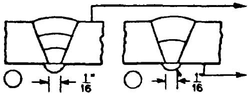
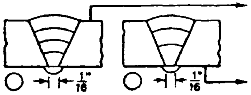
1. In order to avoid slag inclusions (see page 243) the pool of molten parent metal forming the "crater" should be sufficiently fluid and kept so long enough to enable the slag to float to the surface. This condition cannot be obtained with a current setting which is too low.

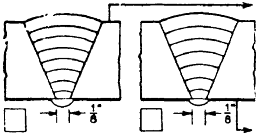
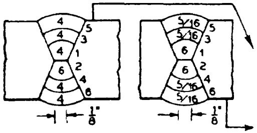
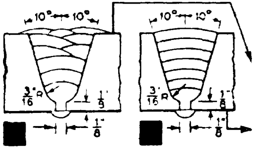
2. The melting and cooling rate of the metal in the welded zone depends to a great extent on size, shape, mass, and location of the parent material adjacent to the weld. Large masses of cold metal, adjacent to or surrounding a weld will retard the heating and accelerate the cooling process, and this must be counteracted by greater heat input, i.e. higher current settings. As an example, inside fillet welds usually require higher current settings than outside corner welds for equal material thicknesses and using the same size of electrode.

3. When welding in the vertical or overhead position care has to be taken to avoid downward flow of molten metal due to gravity. This might occur if the metal is kept too long in the molten state, e.g. through a current setting which is too high. On the other hand, complete fusion has to be obtained, and rather than dropping the current value too much and risking lack of fusion, an increase in welding speed is recommended, thus giving the molten metal no time to flow downwards before it solidifies again.

4. Whilst recommended current settings (see Figs. 2.30–2.32) generally provide the required welding heat without overheating the electrodes, they will not prevent overheating if the welding speed is too slow or the arc too long. In both cases heat will be conducted into the electrode itself, and rather than blaming the current setting, the welder's handling of the electrode should be held responsible for overheating of the electrodes and bad welding conditions.

Automatic Metal-Arc Welding. For producing long welded seams economically, and for obtaining uniform quality of welds in large quantity production, various types of automatic or continuous metal-arc welding equipment have been developed with special devices for feeding the electrode towards the parent material, in order to maintain constant arc length, as the electrode shortens owing to its molten particles dropping into the welded seam. Such an automatic welding head is shown in Fig. 2.33. The coated electrode wire is coiled on a reel *a* and automatically fed towards the work to be welded *b* by means of feeding rollers *c*, after passing through a set of straightening

DIMENSIONS OF WELD PLATE THICKNESS	WELDING PROCEDURE				
	60° Vee preparations for downhand welding, unless shown otherwise	*Number of runs*	*Gauge of electrode*	*Length of weld per electrode*	*Welding current*
In.	*Preparation*	*No.*	*S.W.G.*	*Gauge/In.*	*Amps*
$\frac{1}{8}$		2	8	8/21	170
		1	8	8/14½	170
$\frac{3}{16}$		1 1	10 10	10/15 10/11	100 120
		1 1	10 8	10/15 8/16½	100 170
$\frac{1}{4}$		1 1	10 8	10/15 8/9	100 170
		1 1	10 6	10/15 6/12	100 210
$\frac{5}{16}$		1 2	10 8	10/12 8/12	100 170
		1 1	10 6	10/12 6/8	100 210
$\frac{3}{8}$		1 3	10 8	10/12 8/12	100 170
		1 2	10 6	10/12 6/12	100 210

DIMENSIONS OF WELD PLATE THICKNESS	WELDING PROCEDURE]				
	60° Vee preparations for downhand welding, unless shown otherwise	*Number of runs*	*Gauge of electrode*	*Length of weld per electrode*	*Welding current*
In.	*Preparation*	*No.*	*S.W.G.*	*Gauge/In.*	*Amps.*
$\frac{7}{8}$		1 3 1 2 1	6 4 4 4 4	6/12 4/12 4/9 4/6 4/4	190 250
		1 2 3 1	6 4 4 4	6/12 4/12 4/8 4/6	190 300
		1 1 2 2	4 6 4 4	4/19 6/16½ 4/12 4/8	340 240 340 340
		2 2 2	6 $\frac{5}{16}$ $\frac{5}{16}$	6/15 $\frac{5}{16}$/12 $\frac{5}{16}$/16½	200 560 560
		1 9	4 4	4/20 4/12	240 340
		1 6	4 $\frac{5}{16}$	4/20 $\frac{5}{16}$/12	240 560

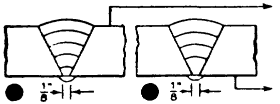
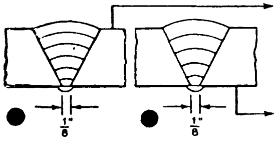
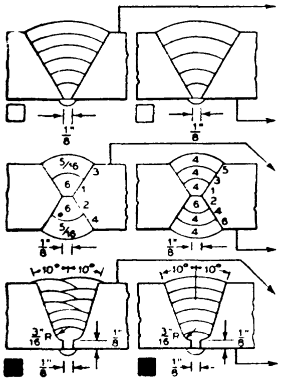
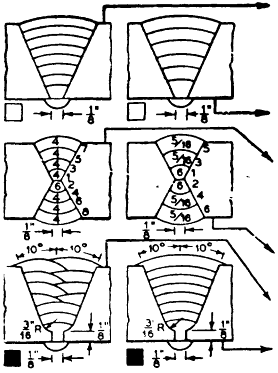
$\frac{1}{2}$		3 2	8 8	8/12 8/7	150 170
		1 1 2	8 6 6	8/12 6/12 6/9	150 210
$\frac{5}{8}$		1 3 1 1	8 8 8 8	8/12 8/9 8/6 8/5	150 170
		1 1 1 1 1	8 6 6 6 6	8/12 6/12 6/10 6/6 6/5½	150 210
$\frac{3}{4}$		1 1 1 1 2	8 6 6 6 6	8/12 6/12 6/10 6/9 6/6	150 210
		1 2 2	8 4 4	8/12 4/12 4/6	150 250
		2 2	6 $\frac{5}{16}$	6/16½ $\frac{5}{16}$/12	200 560
		1 1 2 2	4 6 4 4	4/16½ 6/16½ 4/12 4/9	340 240 340 340
		1 8	4 4	4/20 4/12	240 340
		1 5	4 $\frac{5}{16}$	4/20 $\frac{5}{16}$/12	240 560
1		1 5 2	6 4 4	6/12 4/12 4/6	190 300
		1 2 1 2	6 $\frac{5}{16}$ $\frac{5}{16}$ $\frac{5}{16}$	6/12 $\frac{5}{16}$/12 $\frac{5}{16}$/11 $\frac{5}{16}$/8	190 430
		1 1 4 2	4 6 4 4	4/16½ 6/20 4/12 4/9	240 240 340 340
		2 4	6 $\frac{5}{16}$	6/15 $\frac{5}{16}$/12	200 560
		1 10	4 4	4/20 4/12	240 340
		1 7	4 $\frac{5}{16}$	4/20 $\frac{5}{16}$/12	240 560
○	**KEY TO SEALING RUNS**	1	10	10/16½	120
●		1	8	8/16½	170
□		1	6	6/16½	210
■		1	4	4/12	340

Fig. 2.30. Data for butt welds: downhand welding. Recommended settings for Fastex 5 electrodes.

(*Murex Welding Processes Ltd.*)

The arrows indicate the groups of figures corresponding to the respective diagrams.

DIMENSIONS OF WELD		WELDING PROCEDURE			
Size of fillet	*Throat thickness*	*Number of runs*	*Gauge of electrode*	*Length of weld per electrode*	*Welding current*
In.	*In.*	*No.*	*S.W.G.*	*Gauge/ In.*	*Amps.*
$\frac{1}{8}$	0·088	1	10	10/16½	120
		1	8	8/26½	170
$\frac{3}{16}$	0·133	1	10	10/8	120
		1	8	8/10	170
		1	6	6/22	210
$\frac{1}{4}$	0·176	1 1	10 10	10/12 10/6	120 120
		2	8	8/12	170
		1	6	6/12	210
		1	4	4/18	250
$\frac{5}{16}$	0·221	2 1	10 10	10/12 10/6	120 120
		2 1	8 8	8/12 8/22	170 170
		2	6	6/12	210
		1	4	4/13	250
$\frac{3}{8}$	0·265	1 2	10 10	10/12 10/6	120 120
		1 1	8 8	8/12 8/6	170 170
		1 1	6 6	6/12 6/9	210 210
		1	4	4/8	250
$\frac{1}{2}$	0·354	1 2	8 8	8/12 8/6	170 170
		3 1	6 6	6/12 6/19	210 210
		2 1	4 4	4/12 4/25	250 250
$\frac{5}{8}$	0·441	1 3	8 8	8/9 8/6	170 170
		1 2	6 6	6/9 6/6	210 210
		2 1	4 4	4/12 4/8	250 250
$\frac{3}{4}$	0·530	1 3 1	8 8 8	8/12 8/6 8/4	170 170 170
		1 3	6 6	6/9 6/6	210 210
		1 2	4 4	4/9 4/6	250 250
$\frac{7}{8}$	0·618	1 7	8 8	8/12 8/6	170 170
		2 4	6 6	6/12 6/6	210 210
		1 3	4 4	4/12 4/6	250 250
1	0·707	1 10	8 8	8/12 8/6	170 170
		2 6	6 6	6/12 6/6	210 210
		2 4	4 4	4/12 4/6	250 250

KEY TO PROCEDURE
showing methods for various numbers of runs

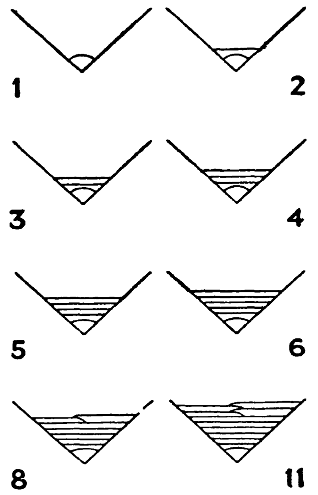


Fig. 2.31. Tilted fillets, scribed to size. Recommended settings for Fastex 5 electrodes.
(Murex Welding Processes Ltd.)

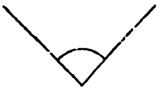
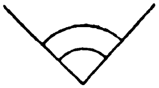
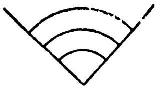
DIMENSIONS OF WELD		WELDING PROCEDURE				KEY TO PROCEDURE *showing methods for various numbers of runs*
Size of fillet	*Throat thickness*	*Number of runs*	*Gauge of electrode*	*Length of weld per electrode*	*Welding current*	
In.	*In.*	*No.*	*S.W.G. In.*	*Gauge/ in.*	*Amps.*	
3/16	0·133	1	1/4	1/4/28	320	 **I RUN**
1/4	0·176	1	1/4	1/4/20	320	
5/16	0·221	1	5/16	5/16/21	450	
3/8	0·265	1	5/16	5/16/14	450	
3/8	0·265	1	3/8	3/8/18	580	 **2 RUNS**
1/2	0·354	1	5/16	5/16/9	480	
1/2	0·354	1	3/8	3/8/14	580	
5/8	0·441	2	5/16	5/16/10	480	
5/8	0·441	2	3/8	3/8/14	580	 **3 RUNS**
3/4	0·530	3	5/16	5/16/9	480	
3/4	0·530	3	3/8	3/8/13	580	

Fig. 2.32. Tilted fillets, scribed to size. Recommended settings for Fastex .5 electrodes. (*Murex Welding Processes Ltd.*)

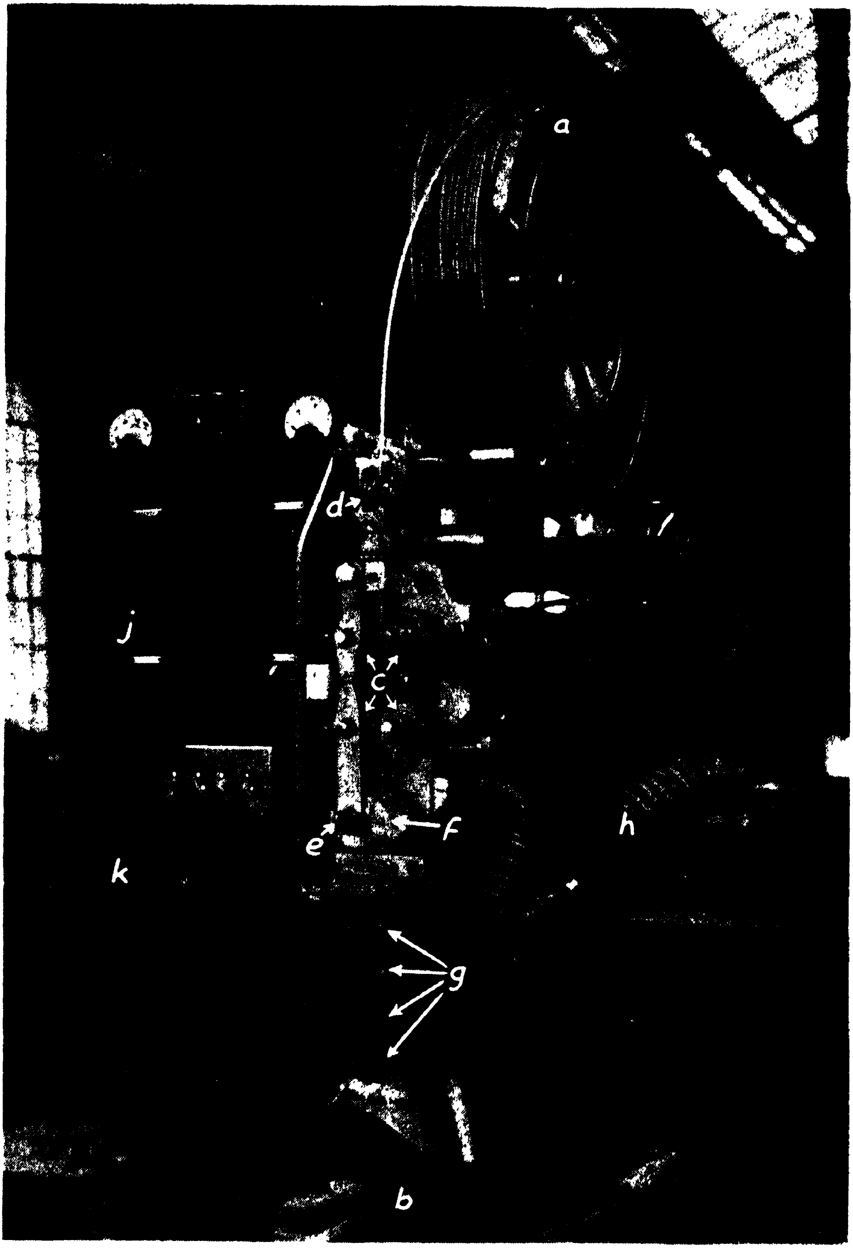


Fig. 2.33. Automatic Metal-Arc Welding Head (*Metropolitan-Vickers*)

rollers *d*. Below the feeding rollers *c* the electrode wire is held by roller *e* against a motor-driven cutter in housing *f*, which mills a slot in the coating. This slot allows the spring-loaded brushes *g* to transmit the welding current to the electrode metal. The brushes are close above the arc, thus reducing to a minimum the current-carrying length of electrode wire. A suction hose *h* is provided for withdrawing welding fumes and milling chips. All settings are adjusted on control panel *j*. The head can move automatically along rail *k* or, for producing, for example, circumferential welds on pressure vessels, it can remain stationary, the workpiece being rotated by manipulating rollers or wheels (Fig. 2.34).

An automatic metal-arc welding process, using bare electrode wire

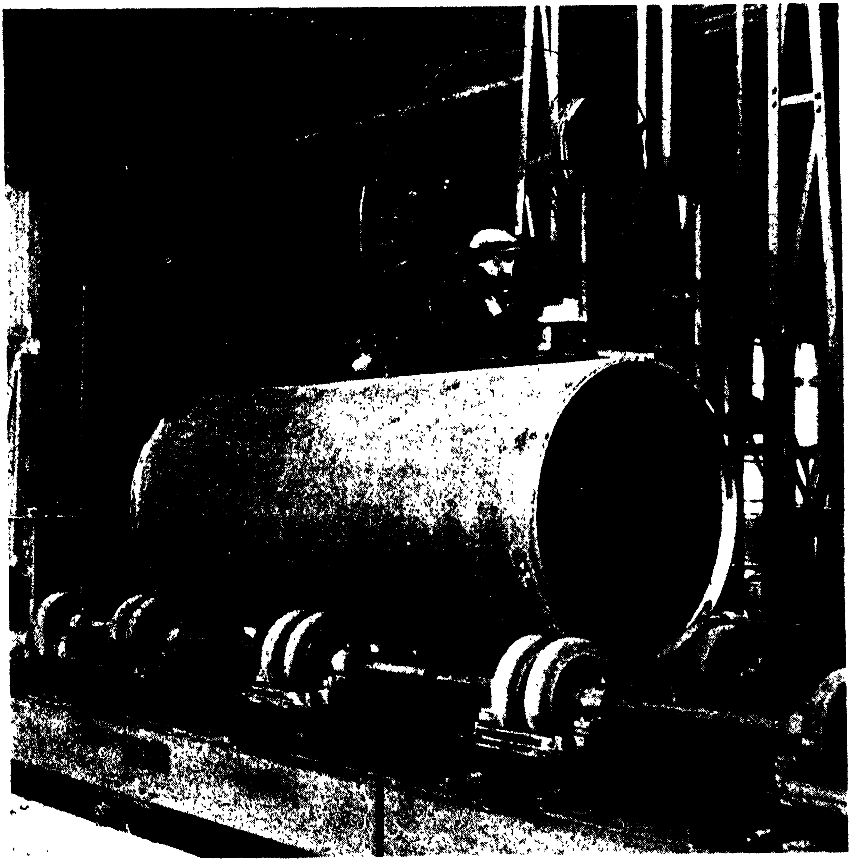


Fig. 2.34. Automatic Metal-Arc Welder producing a circumferential seam on a cylindrical vessel (*Metropolitan-Vickers*).

with the addition of a flux, is the Unionmelt process. In this process a flux in granulated form is deposited on the joint faces before the welding operation begins. The arc between the steel electrode and the base material lies beneath the surface of the flux (submerged arc) thus avoiding spatter and the emission of light, which are both inconvenient and dangerous. Fig. 2.35 shows the principle. The granulated Unionmelt flux is supplied through a feeder tube which is immediately followed by the copper-coated steel electrode. The electrode wire is unwound from a drum and passes between feeding rollers which keep the arc at the required length. The Unionmelt flux is completely fluid at 1300°C., i.e. below the melting point of the steel material. The fused flux material solidifies after the welding and forms the covering slag which cracks away on cooling. The unfused flux material is then removed, and may be collected and used again. Due to the good protection given by the flux to the fused metal, the Unionmelt weld is of high quality. In portable equipment the Unionmelt feed tube and the drum carrying the welding rod wire are arranged in a welding head which travels on a rail above the plate edges to be welded.

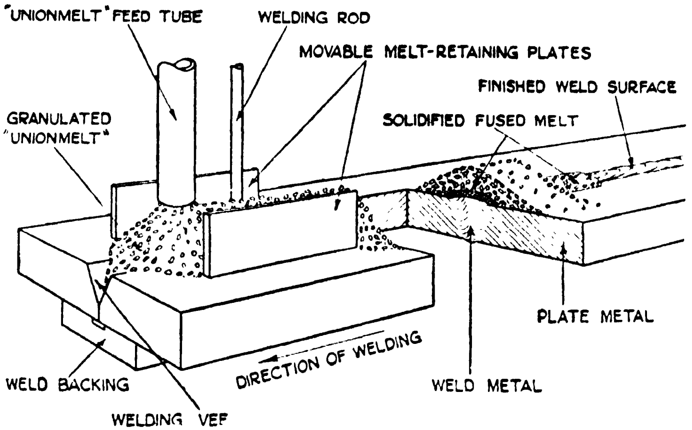


Fig. 2.35. Unionmelt Process (*B.O.C.*)

Stud Welding. This is an interesting application of metal-arc welding, used for welding studs to plate material. It saves the drilling and tapping usually needed for such work. The stud acts as electrode and is held in a hand tool.[1] (Fig. 2.36) at right angles to the plate. When trigger button *a* is pressed the current flowing through stud and plate energizes solenoid *b* which lifts chuck *c*, and with it stud *d*, for a predetermined controlled distance off the plate, thus causing an arc between stud and plate. After a predetermined and controlled time—according

---

[1] The material used for showing the principle of the Nelson Stud Welder has been kindly provided by Cooke and Ferguson Ltd., Manchester.

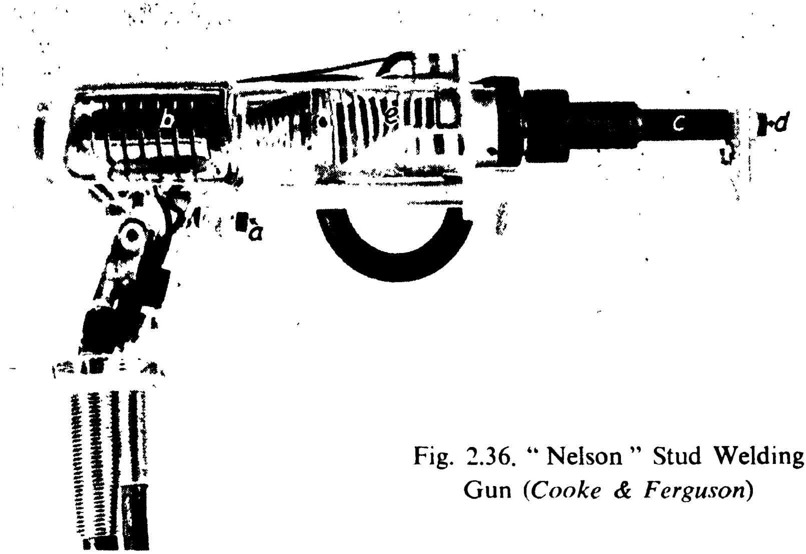


Fig. 2.36. " Nelson " Stud Welding Gun (*Cooke & Ferguson*)

to type and size of studs to be welded—solenoid *b* releases the chuck either before (Cyc-Arc) or after (Nelson) the welding current is cut off (see page 158), and spring *e* presses stud *d* into the molten pool created by the arc. The weld solidifies, creating a slight fillet round the stud base as visible in the sectioned stud (Fig. 2.37).

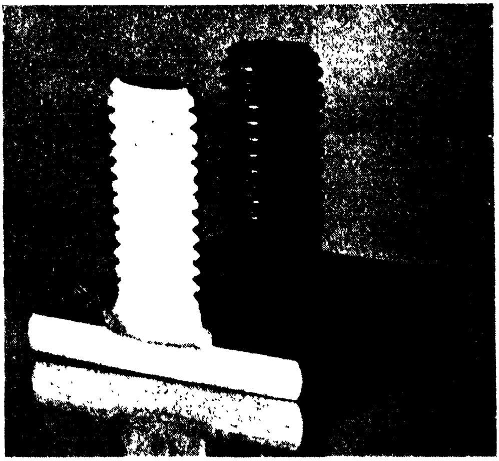


Fig. 2.37

Prepared studs are generally used, a flux being incorporated in the end to be welded. The flux acts as a cleansing medium, especially to prevent oxidation of the weld metal. To prevent spatter and to control the arc, particularly for overhead welding, ferrules are often used (Fig. 2.38).

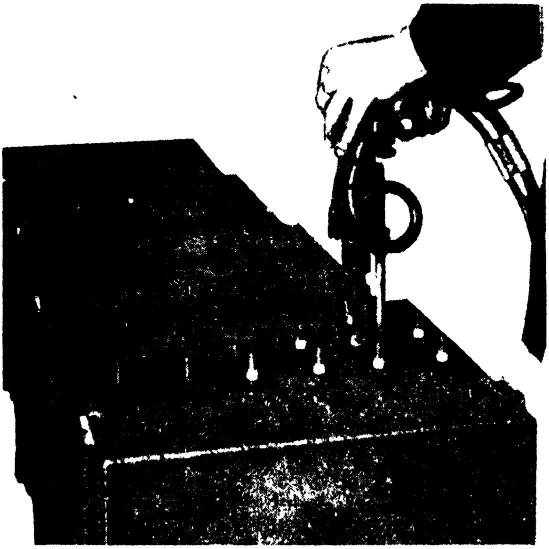


Fig. 2.38. Stud Welding, showing ferrules which are afterwards broken off *(Cooke & Ferguson)*

CHAPTER III

FUSION WELDING PROCESSES (*continued*)

Atomic Hydrogen Welding. To produce the atomic hydrogen flame we need *electrical plant* for producing and controlling the arc between the tungsten electrodes, *gas plant* for producing and supplying hydrogen, and the *welding torch* carrying the tungsten electrodes and the hydrogen nozzle. A.C. is generally used because: (*a*) the usual factory power supply is A.C., and transformers are more economical and easier to maintain than A.C. driven D.C. generators (see page 28); (*b*) current regulation by means of a variable reactance in an A.C. circuit is more efficient than the use of resistances in a D.C. supply; (*c*) electrode consumption is equal on both electrodes, when A.C. is used.

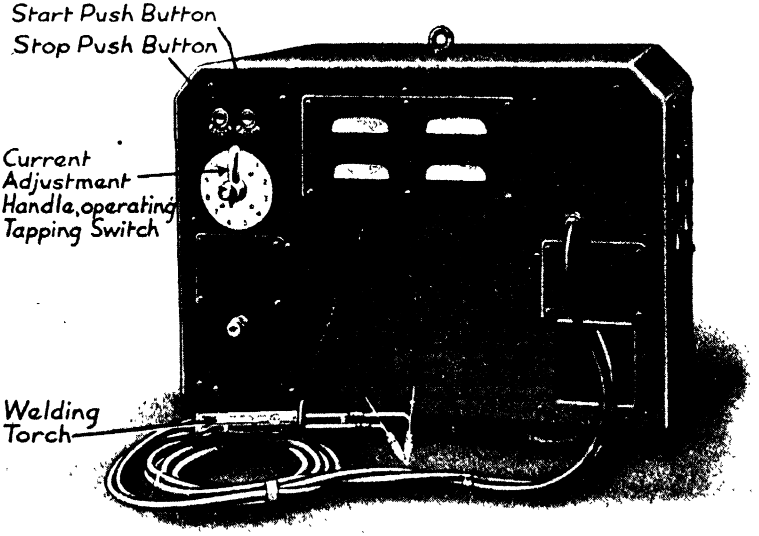


Fig. 3.1. Atomic Hydrogen Welding Control Cabinet (see also Fig. 8.20) (*Metropolitan-Vickers*)

The open circuit voltage required to strike the arc is about 300 volts, and welding currents up to 70 amps. are used at present. The power is obtained by means of a transformer which is combined with current regulation and control equipment in a steel cabinet (Fig. 3.1).

The cabinet contains a transformer, reactor, contactor gear, and an automatic solenoid valve which controls the hydrogen supply, cutting it off automatically when the welding current is switched off, and preventing any waste of gas (see Fig. 8.20). For welding various types and sizes of material the welding current is adjustable by a rotary handle operating a selector switch which taps the welding transformer (see page 160). Push button control for starting and stopping the current is provided. In order to protect the operator, the contactor arrangement is such (see page 160) that the electrodes can only be alive either when the operator uses his free hand, which does not hold the torch, for pressing the starter button or when the arc is struck, i.e. when its heat will in any case preclude his touching them.

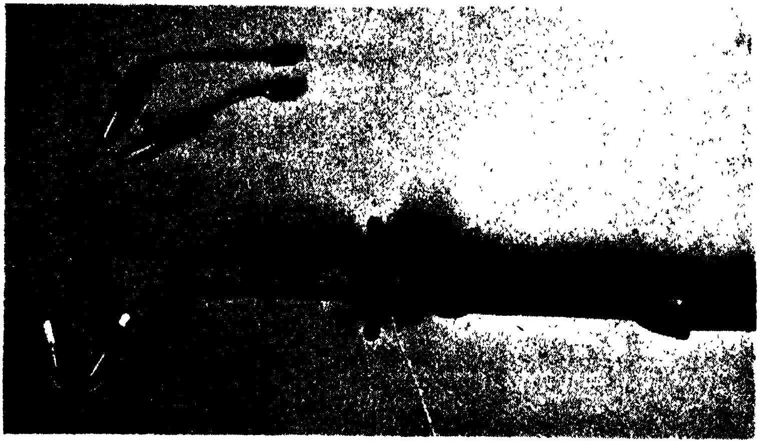


Fig. 3.2. Atomic Hydrogen Welding Torch (*Metropolitan-Vickers*)

The hydrogen is either supplied in compressed form in steel cylinders (painted red) or it is obtained from anhydrous ammonia by means of an ammonia cracker (see page 161 and Fig. 8.21). Anhydrous ammonia (NH_3) is a colourless condensable gas consisting of 75 per cent hydrogen and 25 per cent nitrogen by volume. As the liquid has a vapour pressure of only 7·2 atmospheres at 15°C., the dead weight of material required for ammonia cylinders is much less than it would be for cylinders carrying the same quantity of compressed hydrogen. On the other hand, bottled hydrogen is available at any time, whilst it takes about thirty minutes to heat the ammonia cracker up to the required temperature. It is recommended, therefore, not to use cracker gas if the total gas consumption in a welding shop is less than 250 cubic feet per day, because otherwise the proportion of time lost in switching the cracker on and off would be excessive. At a gas consumption of 1000 cubic feet per day, the cost of cracker gas is about two thirds of that of a corresponding quantity of bottled hydrogen.[1]

The ammonia cracker splits the anhydrous ammonia by passing it through a heated chamber in the presence of a catalyst (see page 162), and produces 180 cubic feet per hour of "cracker gas", containing 75 per cent hydrogen and 25 per cent nitrogen by volume, the residual non-cracked ammonia gas being less than 0·1 per cent.

When using cracker gas, the nitrogen goes through the welding torch together with the hydrogen, but it is inert and has no effect whatever on the quality of the weld. In order to obtain the full amount of hydrogen through the torch, and to let the nitrogen pass through at the same time, the cross section of the gas tubing has to be larger when using cracker gas than when using pure hydrogen.

The welding torch (Fig. 3.2) is connected to the transformer by a two-core cable, and to the hydrogen cylinder or the ammonia cracker by a rubber tube (Fig. 3.1). Thumb wheel *a* (Fig. 3.2) serves for moving electrode *b* towards or away from electrode *c*, thus varying the arc-gap according to the requirements of the job. Various types of electrode holders, with different electrode angles *d*, *e* may be fitted to the torch as and when accessibility of the job requires them. The tungsten electrodes are clamped in the nozzle heads, so that the jet of molecular hydrogen is directed to the arc.

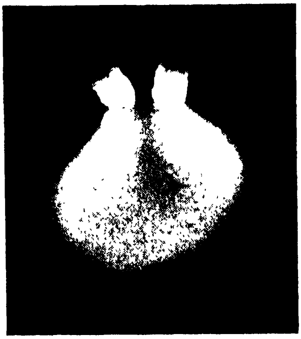


Fig. 3.3. Atomic Hydrogen Flame (*Metropolitan-Vickers*)

The actual welding is carried out similarly to oxy-acetylene welding. The operator holds the torch with his right hand in such a position that the bottom of the elliptically-shaped atomic hydrogen arc flame (Fig. 3.3) is in contact with the metal to be welded. Filler metal is added, when required, by dipping the filler rod—held in the left hand—into the molten pool of the parent metal. Current settings for welding mild steel are shown on Tables 17 and 18.

---

[1] See I. H. Hogg, "Atomic Hydrogen Welding," *Metropolitan-Vickers Gazette*, October 1945.

TABLE 17

Current Settings for Hand Atomic Hydrogen Welding of Mild Steel[1]

Sheet thickness (inches)	Welding current (amps.)
$\frac{1}{32}$	20
$\frac{1}{16}$	27
$\frac{3}{32}$	34
$\frac{1}{8}$	40

[1] Metropolitan-Vickers Electrical Co., Ltd., Manchester

TABLE 18

Current Settings for Automatic Atomic Hydrogen Welding of Mild Steel[2]

Sheet thickness (inches)	Welding current (amps.)
$\frac{1}{32}$	22
$\frac{1}{16}$	48
$\frac{3}{32}$	70
$\frac{1}{8}$	70

[2] Metropolitan-Vickers Electrical Co., Ltd., Manchester

The weld metal produced by the atomic hydrogen process does not contain more hydrogen or nitrogen than that produced by other processes,[1] and there is no danger, e.g. of hydrogen embrittlement. On the contrary, contamination, particularly oxidation of the weld metal, is usually prevented by the reducing character of the atomic hydrogen flame.

Owing to formation of hydrocarbons, however, the welding flame has a decarburizing character. If the finished weld metal is to have the same carbon content as the parent material, that of the filler rod should be higher.

No loss of other alloying elements of steel has been observed in atomic hydrogen welding, and filler rods of various composition are successfully used for the welding of alloy steels (see page 109).

[1] See I. H. Hogg, op. cit.

Automatic welding heads work in general on the same principle as the hand torch. The electrodes are adjustable by means of handwheels. The hydrogen passes through a water-cooled nozzle block, and the housing is asbestos-shielded, in order to protect the mechanism against the heat of the arc.

Thermit Welding[1] is a casting process in which a mould is first built round the portions of the components near the weld and the gap is filled by molten metal resulting from the chemical reaction between iron-oxide and aluminium (see page 7). This reaction is initiated by heating the iron-oxide and the aluminium to a certain temperature. The molten filler material fuses with the parts of the adjacent parent material.

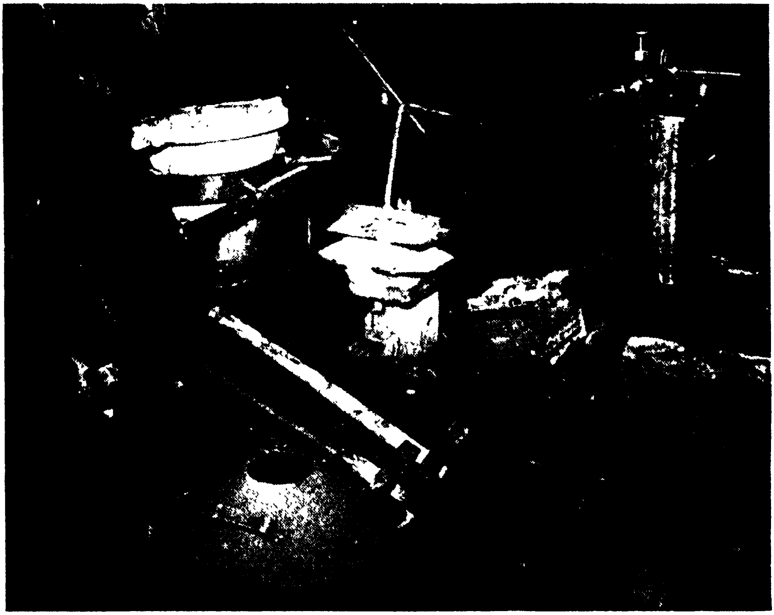


Fig. 3.4. Thermit Welding Equipment (*Murex*)

The equipment can be seen from Fig. 3.4 which shows a welding operation to connect rails. The mould surrounds the rail section to be welded, and the molten weld metal is poured into it from a crucible after mould and rails have been preheated (the paraffin preheater is seen).

---

[1] Most of the information contained in this chapter has been kindly supplied by Messrs. Murex Ltd., Rainham, Essex.

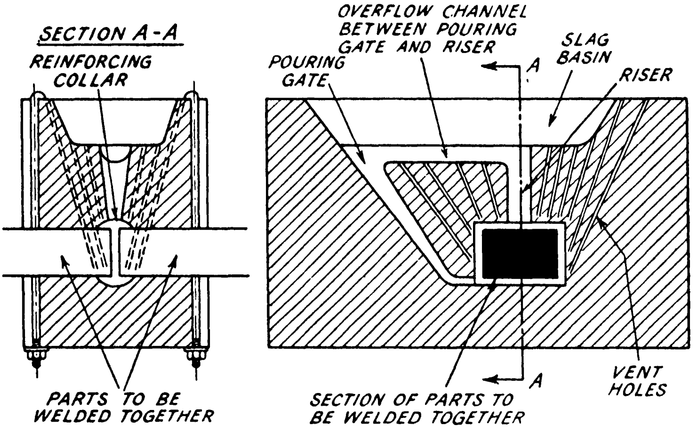

SECTION A-A
REINFORCING COLLAR
PARTS TO BE WELDED TOGETHER
OVERFLOW CHANNEL BETWEEN POURING GATE AND RISER
POURING GATE
A
SLAG BASIN
RISER
VENT HOLES
SECTION OF PARTS TO BE WELDED TOGETHER
A

Fig. 3.5

The *mould* is made from moulding sand which should be free from carbonates and sufficiently coarse to allow for the necessary ventilation. It is usually built inside a mould box of sheet iron, as shown in the section through a mould for welding two heavy rectangular sections (Fig. 3.5). Pouring gate and risers, similar to those in ordinary casting moulds are provided. The metal filling these has to be removed afterwards (Fig. 3.6). Vent holes (up to ¼″ diameter) allow the gases to escape.

The mould fits tightly round the sections to be welded, but round the actual weld a reinforcing collar is allowed which can be removed where required (Fig. 3.5). Before the molten metal is poured into the mould, the ends of the components to be welded have to be cleaned from scale, grease, dirt, and rust, and are then preheated to a temperature of about 600–900°C.

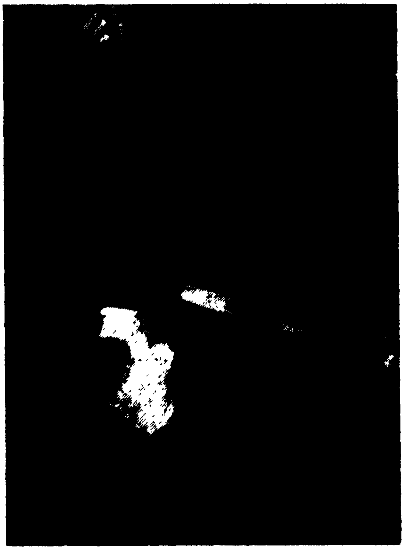


Fig. 3.6. Removing Surplus Metal after Thermit Welding (*Murex*)

The *crucible* is usually lined with dead burned magnesite, which is a high grade refractory. When fitted with a tapping hole at the bottom, the crucible is usually mounted on a stand so that the hole is not more than 6″ above the pouring gate in the mould. It is plugged by means of an asbestos disc *c* covered by a steel disc *d* (Fig. 3.7).

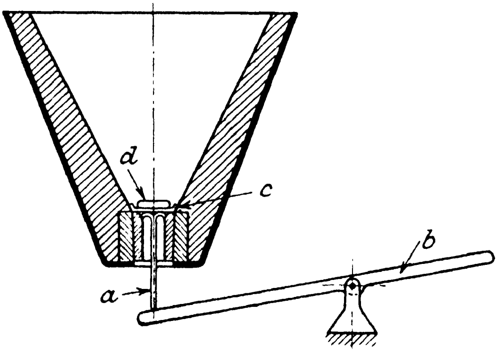


Fig. 3.7

After plugging the tapping hole, the operator fills the crucible with slightly *more* Thermit compound than is required for filling the mould, risers, and pouring gate, since the weld must not be spoiled by lack of filler metal. About a teaspoonful of ignition powder (see page 6) is placed in the top centre of the compound, and the crucible is then covered with a lid. After igniting the charge with a match or a hot iron bar, the operator waits until the Thermit reaction is complete (see page 7), and until the molten iron has settled at the bottom of the crucible, which is now covered by the superheated slag (Al_2O_3). He then taps the crucible by lifting tapping pin (*a*, Fig. 3.7) either directly by a sharp upward blow, or indirectly by means of lever *b*, thus knocking away asbestos disc *c* and steel plate *d* and opening the way for the molten metal. The metal then pours into the mould, with the following slag being guided away or settling in the basin provided on top of the mould (see Fig. 3.5). In some cases a tilting crucible is used from which the slag flows out first and passes through the mould, finally remaining in the riser portion.

A combined fusion-and-pressure welding process, the "Butt" Thermit process, is sometimes used for welding rails, particularly if it is feared that the Thermit iron in the weld will not be of the same hardness as the rail material itself, thus causing weakness. In this process[1] the Thermit iron fills the bottom part only of the mould, while the top of the rails and a correctly profiled shim of rail steel in the gap are heated up by the molten slag and forced together by mechanical means to form a forged butt weld. Fig. 3.8 shows the welding of rails by this process. Clamps hold the rails and press them together about three minutes after the molten metal and slag have flowed from the crucible into the mould. When using this process at least one rail has to be movable, and the pressing has to be carried out with great care in order to minimize the longitudinal movement of the rails. For these reasons, and because of the increased cost of equipment, the ordinary fusion process is considered advantageous, particularly as it is claimed that with modern Thermit compound weld metal can be obtained which has the same properties as the parent rail material.

---

[1] See F. C. Mannox, "The Continuous Rail," *Passenger Transport*, August 8th, 1947.

It is considered that welds below 10 square inches in area, and those connecting very thin and critically shaped components are not economically suitable for the Thermit process. Theoretically the maximum size is only limited by that of crucibles and moulds.

An interesting large-size repair carried out by Thermit welding is shown in Fig. 3.9. A fracture in a 27″-diameter pinion shaft was

Fig. 3.8. " Butt " Thermit Welding Rails (*Murex*)

repaired by cutting off the fractured end and replacing it by a new forging. The metal filling pouring-gate, preheating ports and riser, can be clearly seen from the photograph which shows the parts after welding and after the mould box has been removed.

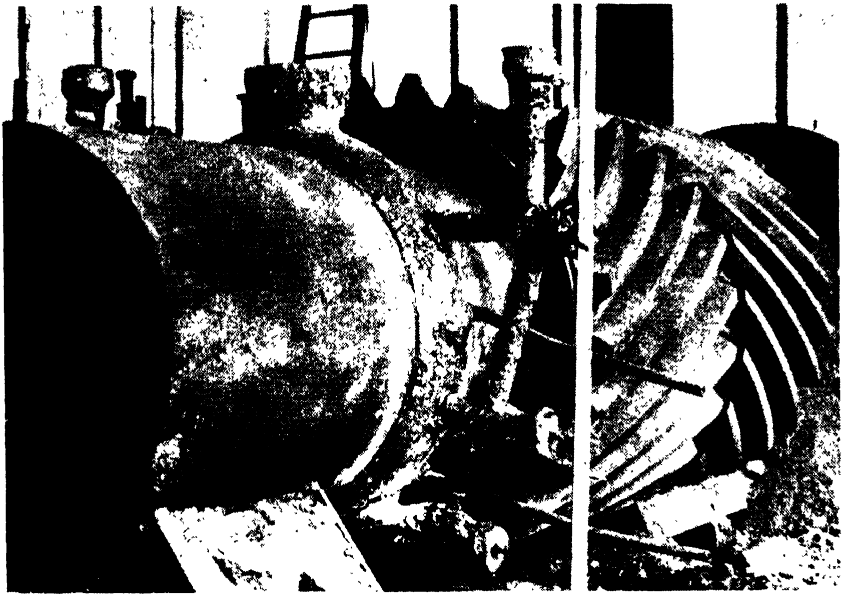


Fig. 3.9. Repair of a Pinion Shaft by Thermit Welding (*Murex*)

CHAPTER IV

FORGE WELDING PROCESSES

Principal Features. In forge welding processes, heat brings the material to the forging temperature, and pressure forges the component parts together.

In *oxy-acetylene pressure welding* the ends of the components to be welded are heated (not necessarily to the melting temperature), and are then forged together by means of pressure applied to the components. The finished joint is similar in appearance to resistance welded butt joints (see page 10). A typical arrangement of a burner for heating tubular sections is shown in Fig. 4.1.[1]

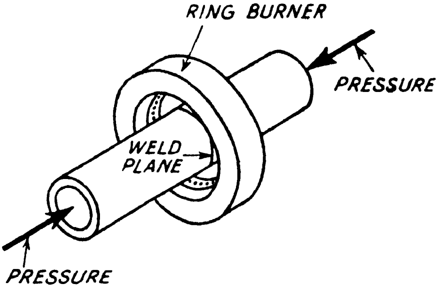


Fig. 4.1

In *resistance welding,* the pressure also serves for creating the necessary contact conditions to obtain good current-flow. A current passing through the components at the point or points to be welded creates the heat, and mechanical means (lever arrangements, hydraulic or pneumatic devices) usually provide the pressure.

The heat H created by the welding current in the components at the points to be welded, depends upon the electrical resistance R of the metal between the electrodes including the contact resistance, the square of the welding current I, the time T of current-flow, and the radiation and convection losses at the electrodes and in the material surrounding the weld (factor k) according to the relation:

---

[1] From J. L. Zambrow and R. D. Williams, " Pressure Gas Welding of Alloy Steel Tubing," Research Supplement, *Welding Journal,* October 1946

$$H=k\ R\ I^2\ T$$

The magnitude of the resistance value R depends upon the type and size of materials to be welded, and can be taken as a given constant value, if the contact conditions (cleanness of surfaces, shape, size and surface condition of electrode tips, electrode pressure) are in accordance with standard requirements. It should be mentioned that this equation does not completely apply to flash-butt welding where flashing and arcing cause additional heat.

The state of the material surfaces is particularly important in the case of spot and projection welding. Whilst slight rust, or mill scale, on the material may not much affect the efficiency of arc welds, lack of cleanness will be fatal to resistance welded joints. Pickling or shot blasting of the material, prior to spot or projection welding are essential for efficient welds.

Plate material up to $\frac{3}{16}''$ thickness which is to be used for resistance welded jobs is usually purchased in a pickled and slightly oiled condition, and should be carefully stored in order to keep it clean, when it can be used without removing the oil film. Material above $\frac{3}{16}''$ should be shot-blasted shortly before being taken to the resistance welding machines. Long delay incurs the risk of fresh corrosion. Sand blasting is not recommended, as particles of the siliceous material imbedded in the steel surface may influence its electrical resistance.

In the case of spot welding, the diameter d of the electrode tip (see Fig. 1.9) determines the contact area between electrode and plate which will be welded, i.e. the size of the spot weld. It can be generally assumed that the spot diameter roughly equals the electrode tip diameter (see Fig. 1.9). If the latter is too small, weak welds will result, and—due to high specific surface pressure—indentation of the plate material may become excessive. B.S.S. 1140 specifies that the indentation caused by spot welding electrodes must not exceed 10 per cent of the thickness of the sheet material.

Inadequate surface pressure at the electrode tips, due to too large tip diameter, may cause too high contact resistance between electrode tip and plate, and together with the decreased current density may result in porous and weak welds. The electrode tip size has to be chosen in relation to the thickness of the material to be welded, and it has been found empirically that the relation

$$d=\sqrt{t}$$

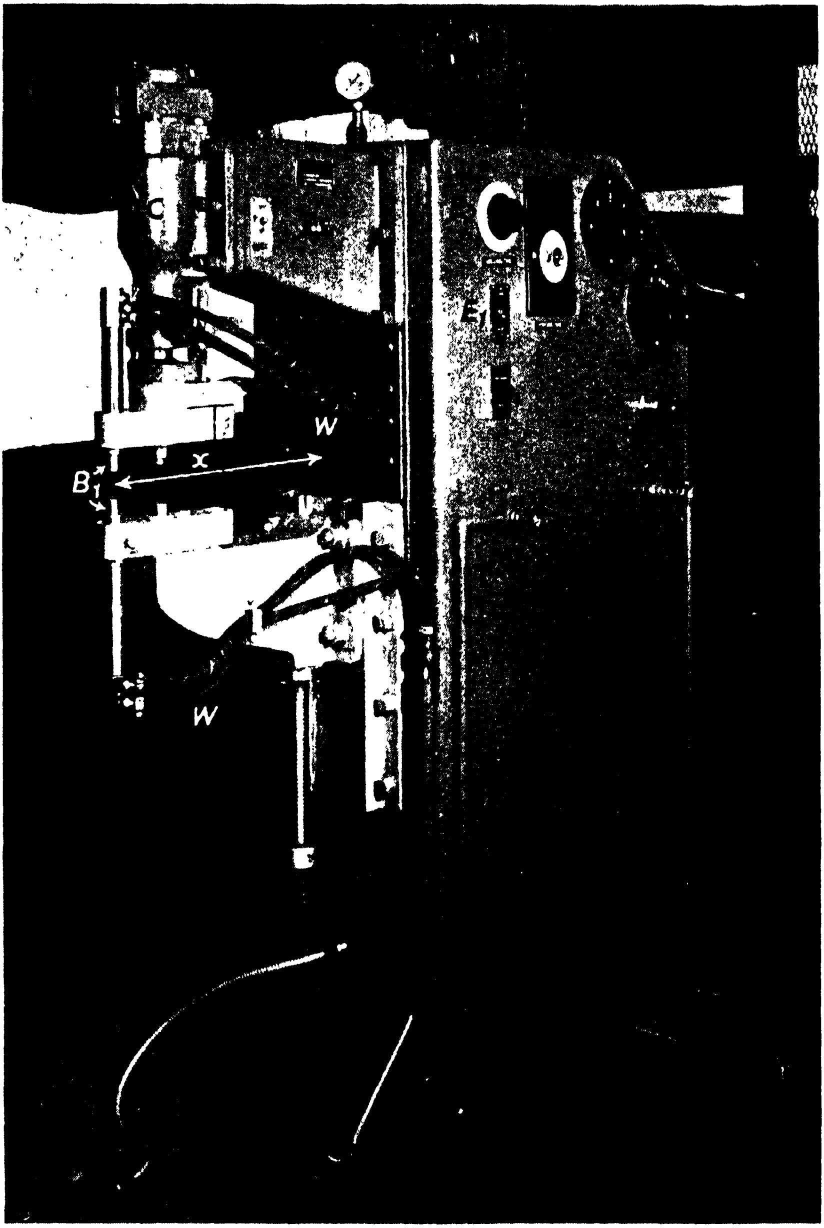


Fig. 4.2. 60 k.v.a. Spot Welder (*Metropolitan-Vickers*)

gives satisfactory results when spot welding mild steel, *d* being the electrode tip diameter and *t* the thickness of the material to be welded (see B.S.S. 1140).

Current Density. In order to keep the current density reasonably constant, the above tip diameter has to be maintained within certain limits. With the continuous heating and pressure, a certain flattening (" mushrooming "), of spot welding electrodes cannot be avoided and electrode tips should be dressed when their diameter has increased by more than $\frac{1}{3}$ of its initial value. (B.S.S. 1140).

This problem does not exist in the other resistance welding processes, where the welding area is independent of the welding machine and its equipment. In projection welding, a platen (see Fig. 1.10) transmits the current to a relatively large surface of the component, and the contact area at the points to be welded depends entirely upon the size and shape of the projections. In butt and flash-butt welding, (see Figs. 1.11, 1.12), the clamping area is again relatively large, and the size of the ends to be welded determines the current density at the welding point. Current density and specific surface pressure between electrodes (platens or clamps) and component material are, therefore, low in the case of these three methods.

As the heat generated in the electrodes is proportional to the resistance of the electrode material, low resistance will, apart from reducing current losses, keep down the temperature of the electrodes. This is important because conductivity, mechanical strength, and resistance to wear of the electrode material are all lowered by greater heat. Moreover, keeping the temperature down will prevent too much heat being generated between electrode and components, instead of being concentrated at the joint faces to be welded.

Cooling the Electrodes. Efficient means of cooling the electrodes have to be provided, and high heat conductivity of the electrode material is required, so that the heat generated can be quickly dissipated. Various copper alloys possess the requisite characteristics and are on the market. Rubber tubes carry cooling water, usually taken from the town supply, to the electrodes and back to the exhaust outlet which empties into the drain. (*W*, Figs. 4.2, 4.3).

Whilst water-cooled platens (B_2, Fig. 4.3) or clamps (B_4, Fig. 4.9) are usually fixtures on projection, butt, or flash-butt welding machines, a great variety of types, shapes, and forms of spot-welding electrodes (B_1, Fig. 4.2) has to be used on spot-welding machines in order to allow for various thicknesses of material, and accessibility of the job

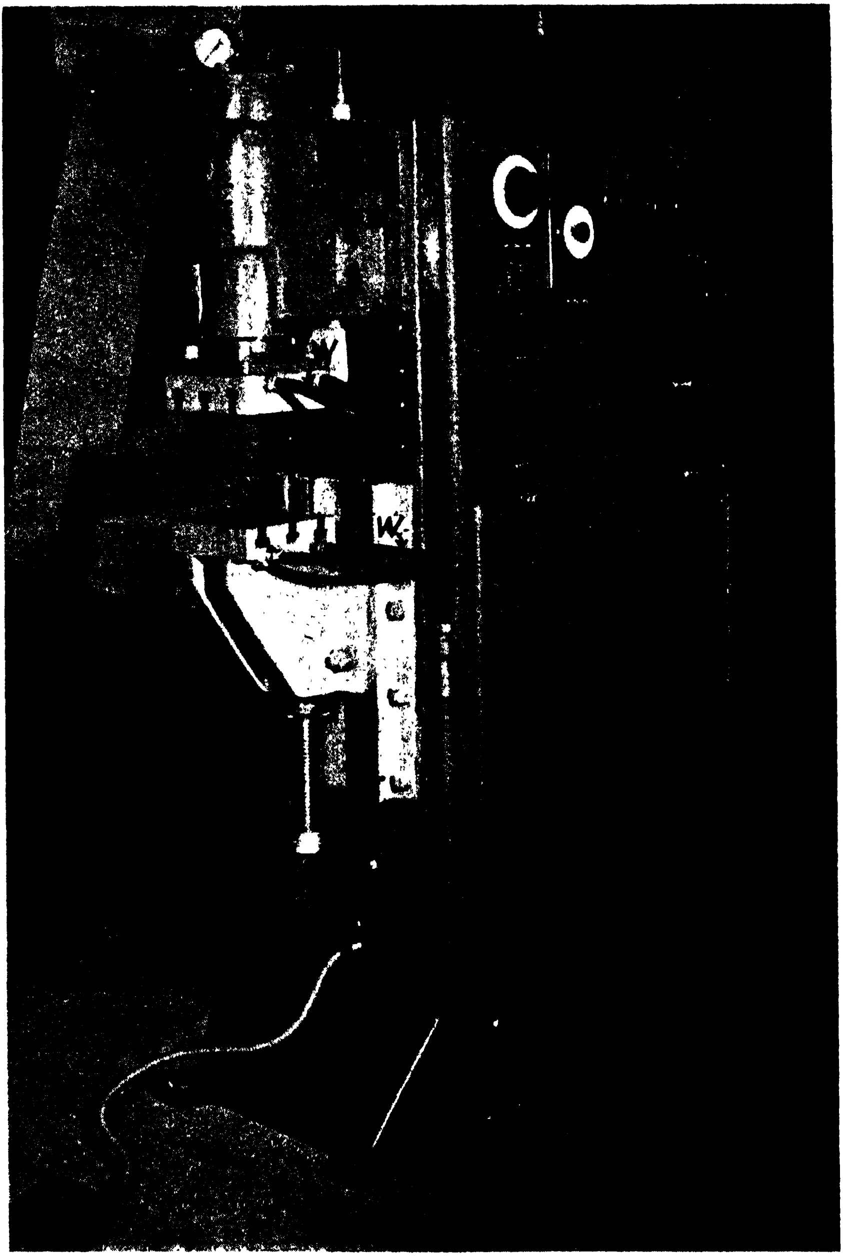


Fig. 4.3. Projection Welder (*Metropolitan-Vickers*)

(Fig. 4.4). Spot-welding electrodes are, therefore, removable and interchangeable, and the electrode holder *a* (Fig. 4.5) is provided with a female morse taper into which fits the male morse taper of the electrode *b* (see B.S.S. 807). Accurate fit is of the greatest importance, as contact resistance between the two and tightness of the water supply line depend on it.

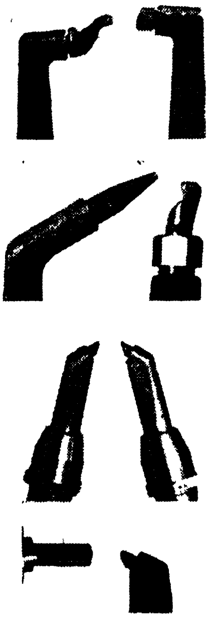


Fig. 4.4. Spot Welding Electrodes (*Sciaky*)

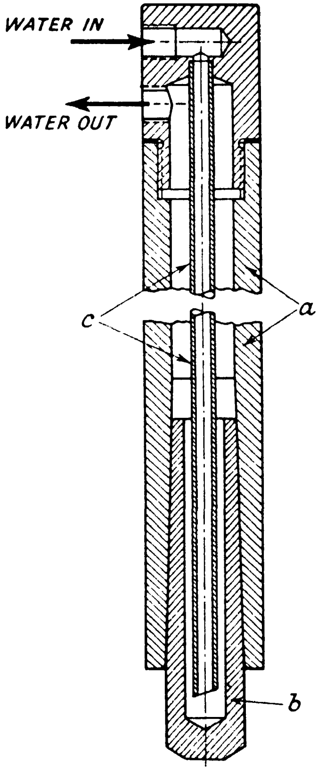


Fig. 4.5

The incoming water supply is fed through a copper pipe *c* inside the electrode holder. This should reach as deep as possible into the bore of the electrode, in order to prevent inefficient cooling through the formation of steam pockets near the electrode tip. B.S.S. 1140 limits the distance between the end of the pipe and the bottom of the hole in the electrode to a maximum of $\frac{3}{8}''$, and the distance between the bottom of the hole in the electrode and the electrode tip, to a maximum of $\frac{1}{2}''$, wherever practicable. The end of the copper tube is usually cut off at an angle (see Fig. 4.5) to avoid blocking the water supply should the electrode be jammed in too far.

On seam welding machines, rotating wheels (B_3, Fig. 4.6) take the place of the electrodes. The cooling water supply (W) to the wheel-bearing brackets is similar to that used for cooling spot-welding

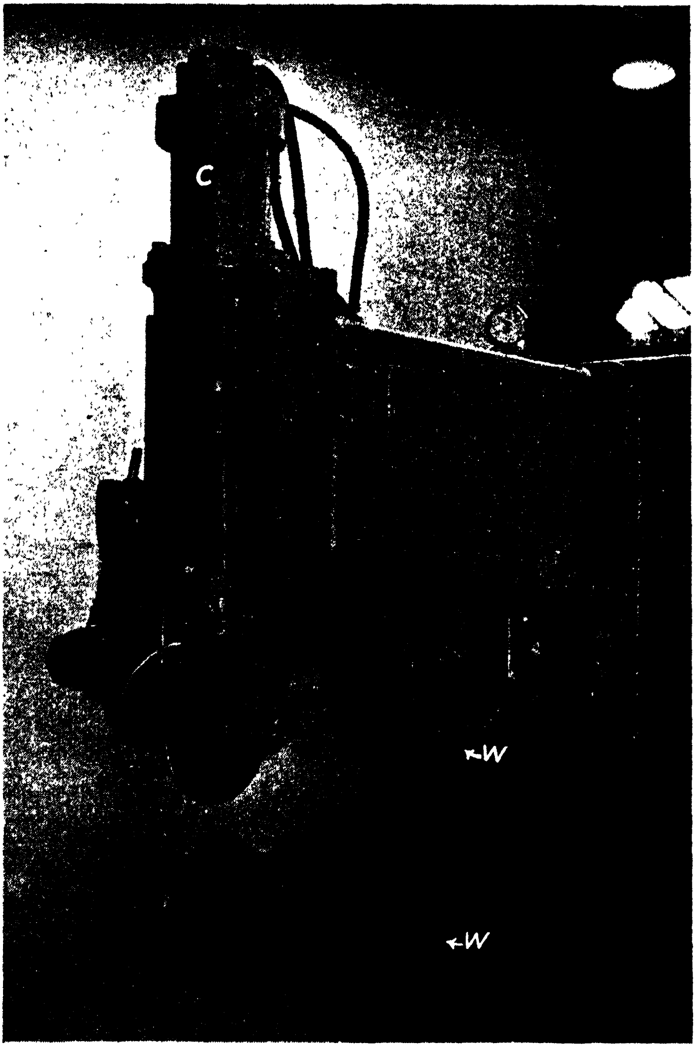


Fig. 4.6. Pressure Head and Electrode Wheels of a typical Seam Welder (*Metropolitan-Vickers*)

electrodes and projection welding platens. To cool the wheels themselves internally, however, would be rather complicated and expensive, and provision is often made to spray them with water externally (tube *w*), at the welding points.

In order to avoid damage to the electrodes through failure of the water supply, a water-flow switch is often provided (Fig. 4.7), which interrupts the current supply if the flow of water drops below a certain value.[1]

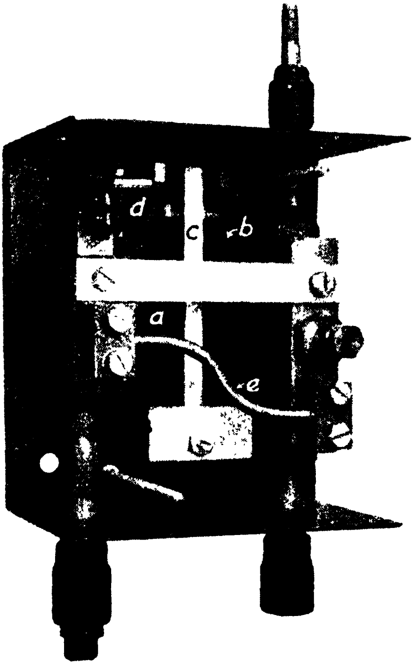


Fig. 4.7. Water-Flow Switch (*B.T.H.*). Two bellows (*a*) and (*b*) operate through lever (*c*) the normally closed micro-gap switch (*d*). Pipe (*e*) connects the inlet side with bellows (*a*), whilst bellows (*b*) are connected to the water outlet controlled by throttle valve (*f*). The pressure in bellows (*a*) will be higher than that in bellows (*b*) as long as water is flowing, and lever (*c*) will be pushed to the right, thus leaving switch (*d*) closed. As soon as the water flow drops below a value determined by the setting of throttle valve (*f*), bellows (*b*), acting on a bigger leverage than bellows (*a*), push lever (*c*) to the left, thus opening switch (*d*) and stopping the current supply to the welding machine.

Pressure Control. The *welding pressure* holds the components together, creates the necessary contact pressure at the points to be welded, breaks down slight films of oil or grease on the faces to be welded, and forges the components together, during and after the current-flow. Foot or hand control of the pressure by the operator's skill and judgment is only used in special cases, e.g. for small hand-operated flash-butt welders. Pneumatic and hydraulic cylinders are the pressure devices mostly used. They have the advantage of easy adjustment to suit the conditions.

---

[1] According to B.S.S. 1140 not less than 1 gallon of water per minute should be used for water-cooling each spot-welding electrode.

A standard compressed-air supply of 80–100 lb. per square inch, as available in most factories, is normally used, and the pressure in the cylinder (*C*, Figs. 4.2, 4.3, 4.6, 4.9) is adjusted by a regulation valve (*G*, Figs. 4.2, 4.3).

Pressure control by means of adjustable springs is used in the case of hand- or foot-operated rocker arm spot welders, or in the case of welding machines operated by motor driven cams, and also when heavy spot welders are used for light duty operations for which even the lowest obtainable air pressure would be too high. In such cases an adjustable spring is inserted between the operating lever, the operating cam, or the pneumatic plunger on the one side and the electrode holder on the other. The movement of the former is limited by positive mechanical action (stroke of the cam, fixed stops which limit the movement of plunger, hand lever, or pedal), and the pressure exerted on the electrodes is determined by the resulting compression of the inserted spring.

Hydraulically or pneumatically operated welding machines are often equipped with a pressure switch in the electric circuit, which starts the weld cycle only when the full pressure is built up in the cylinder.

Welding Current. The welding heat, obtained by an appropriate combination of current and time settings may, according to the heat equation given at the beginning of this chapter, be obtained either with short time—high current, or with long time—low current settings.

The heat radiation and conduction factor " *k* " in the heat equation allows for heat losses into the air surrounding the welds, and for losses due to conduction into the electrodes and into the adjacent metal. This conduction not only represents a waste of heat, but may cause distortion of the material outside the welded zone which should be affected as little as possible. It can be reduced to a minimum by using *shortest possible welding times at highest possible currents.* The lower the electrical resistance of the material to be welded the higher the current required to obtain a given welding heat. As good electrical conductors are usually good conductors of heat, such metals will demand a still larger current by reason of this factor as well. A compromise between all the above-mentioned points and practical limitations has often to be found.

Moreover, radiation and conduction losses grow with increasing temperature and, therefore, above a certain heat input, no increase in the temperature of the welded zone will be obtained by further increasing time or current.

On the other hand, hard spots have been found near and around resistance welded points through short time heating and subsequent chilling of the material. Such hard spots are inconvenient if the face of a plate has to be machined after welding. It has been found that in such cases a slight reduction in current and increase in time evens out the difficulty.

From the foregoing remarks it will be realized that accuracy of the current setting, once it has been determined with reference to these considerations, is of great importance, all the more so as the square of its value appears in the heat equation. The high amperage-low voltage current is usually obtained through a transformer (*A*, Fig. 4.8) and it is general practice to adjust the welding current by tapping its primary winding (*D*, Fig. 4.8). If the steps of the tapping arrangement are too coarse, fine adjustments in the welding time will provide the required accuracy of the welding heat.

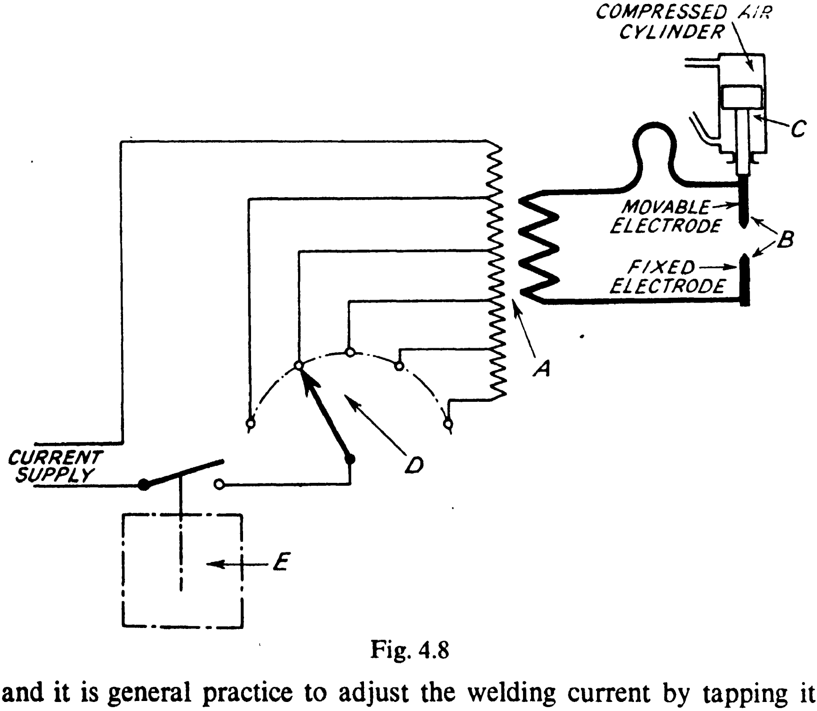


Fig. 4.8

Electronic devices have been developed which, through phase control of the ignitron (see page 168), allow currents to be automatically adjusted even while welding is in progress.

Constant reliability in resistance welding can only be maintained if the welding conditions, particularly the current values, do not vary during the progress of operations. When spot welding large-size steel components, however, which have to be fed more and more into the throat of the welding machine (throat depth x, see Fig. 4.2) the large amount of steel inside the secondary circuit will act as a choke, and will increase the inductance of the circuit, thus reducing the welding current. In case of current control through transformer tappings, this phenomenon has to be allowed for by changing the tappings accordingly, and careful tests have to be made to ensure that the required welding current will be available under actual production conditions. Electronic control gear has also been developed (see page 168) which overcomes this difficulty by keeping the welding current constant, whatever the amount of material in the welding throat may be.

Timing of the welding cycle, i.e. time of application of pressure, welding current, forging pressure, reheating after welding, is only in a few special cases left entirely to the skill of the operator. The majority of modern resistance welding machines provides automatic control for the timing of current and pressure application (*E*, Fig. 4.8).

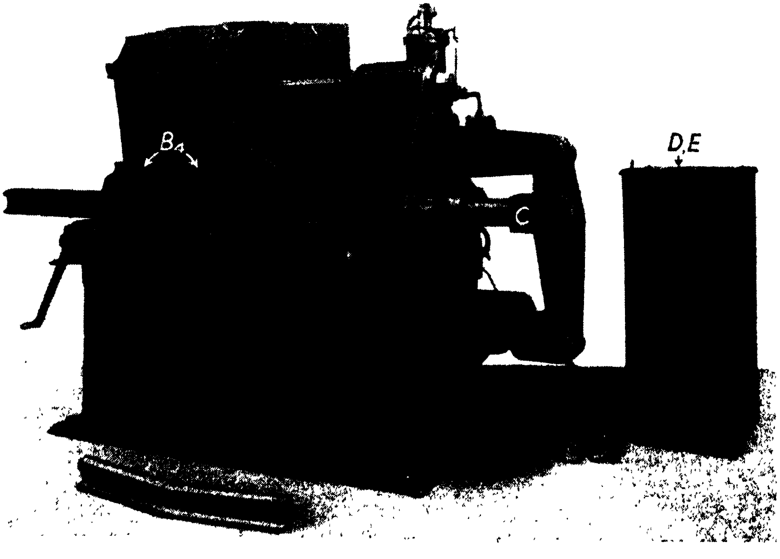
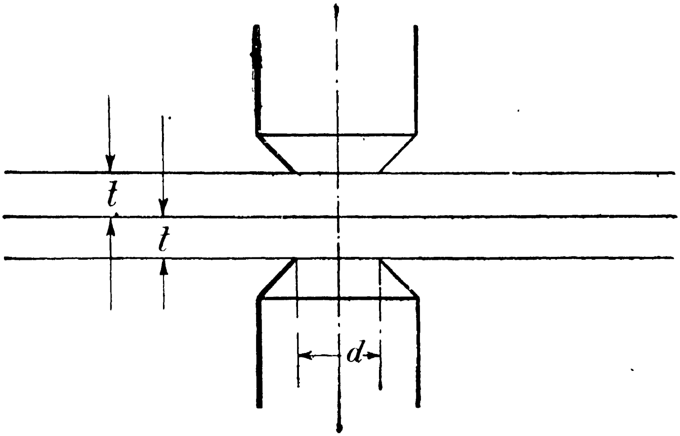


Fig. 4.9. 300 k.v.a. Automatic Flash Butt Welder for rail sections
(A.I Electric)

Mechanical timing devices (see page 165), and electronic controls (see page 166) for timing with the highest degree of accuracy are used. After being adjusted to the required conditions, these devices take control of the complete operation cycle, so as to make it impossible for the operator to interfere, once he has initiated the process by pressing the button or foot switch (Figs. 4.2, 4.3).

TABLE 19

Recommended Settings for Spot Welding Low-Carbon Steel



t		d min.	Welding current	Electrode pressure	Welding time
S.W.G.	inches	inches	amps	lb.	secs.
22	0·028	$\frac{3}{16}$	8000	450	0·1
20	0·036	$\frac{3}{16}$	8000	450	0·1
18	0·048	$\frac{3}{16}$	8000	450	0·1
16	0·064	$\frac{1}{4}$	10000	750	0·2
14	0·080	$\frac{5}{16}$	13000	1200	0·4
12	0·104	$\frac{5}{16}$	13000	1200	0·4
10	0·128	$\frac{3}{8}$	16000	1700	0·6
—	$\frac{3}{16}$	$\frac{7}{16}$	17500	2300	0·8
—	$\frac{1}{4}$	$\frac{1}{2}$	20000	3000	1·4
—	$\frac{3}{8}$	$\frac{5}{8}$	31000	4700	2·0

Resistance Welding Machines consist of (Fig. 4.8):

1. The welding transformer *A* which provides the required high amperage-low voltage current.

2. The current carrying parts *B* which transmit the welding current to the components, i.e. the electrodes B_1 of the spot-welding machine (Fig. 4.2), the platens B_2 of the projection welding machine (Fig. 4.3), the wheels B_3 of the seam welding machine (Fig. 4.6), or the clamps B_4 of the flash-butt welding machine. (Fig. 4.9).

3. The mechanical lever arrangement or hydraulic or pneumatic device *C* which provides the necessary welding pressure.

4. The current-adjusting devices *D* for setting the required welding current.

5. The timing devices *E* which control the weld cycle, e.g. E_1 and E_2 (Figs. 4.2, 4.3) for controlling the time of actual current-flow (welding time), E_3 (Figs. 4.2, 4.3) for controlling the time of pressure application after the current-flow has ceased (forging time).

Spot-welding Settings. Typical data for *spot welding* mild steel plates are shown in Table 19. For a given plate thickness *t*, the value of the electrode tip diameter ($d = \sqrt{t}$) (see page 77) is always given to the nearest $\frac{1}{16}''$.

The welding pressure required is calculated on the basis of a specific pressure of 10,000 lb. per square inch over the electrode tip area. In view of the fact, however, that plates will not always be perfectly flat, a certain additional pressure is usually recommended, which will overcome slight distortion of the plates without reducing the necessary welding pressure.

Current densities vary between 80000 and 200000 amps. per square inch growing with decreasing plate thickness, and the current settings shown have been established empirically.[1] Forging times (holding pressure after the current is cut off) are approximately equal to the welding times.

In connection with the spacing and positioning of spot welds it must be remembered that, once a spot-weld connection has been established between two plates, it will carry part of the current applied for making any subsequent welds (Fig. 4.10). In making these latter welds, the total welding current applied will thus not be available, as it will be reduced by the amount of shunt current flowing through previously made welds. In order to reduce this loss to a permissible minimum, the spacings *s* (see Fig. 1.9) between two welds should be not less than 3 × *d* nor less than ½″, whichever is the greater value. In order to maintain plate stability, however, it is recommended[1] that a spacing of 12 times the plate thickness should not be exceeded in the case of single row spot welds, or 18 times the plate thickness in the case of spot welds arranged in staggered rows. This does not apply to sheets below 16 S.W.G. where the consideration with regard to an electric shunting effect requires larger spacings. It is pointed out, however, that designs using such thin sheets are not likely to be affected by questions of plate stability.

---

[1] See also: Recommended Practice for the Spot Welding of Low Carbon Mild Steel, Interim Report of the FR6 Committee on the Preparation of a Code of Practice for Spot Welding of Mild Steel. *Transactions of the Institute of Welding*, 1948, page 83r.

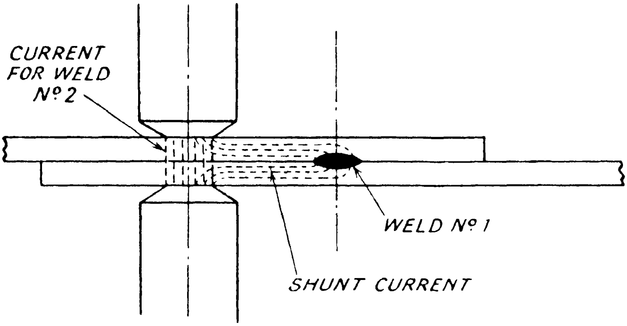


Fig. 4.10

The edge distance *e* (see Fig. 1.9) should be at least 1·5 times the diameter *d*, when the welds will shear before the plates will tear at their edges.

Spot welding has an advantage over projection welding where the number of welds required is relatively small, where the size of the job is too large for the capacity of projection welders, and where the design allows the necessary spacing and arrangement of the welds to be obtained.

Seam-welding settings have to take into account the pitch between the welds, which is determined by the times of applying and interrupting the welding current, and by the wheel speed. Typical machine settings for seam welding mild steel plates are shown in Table 20.[2]

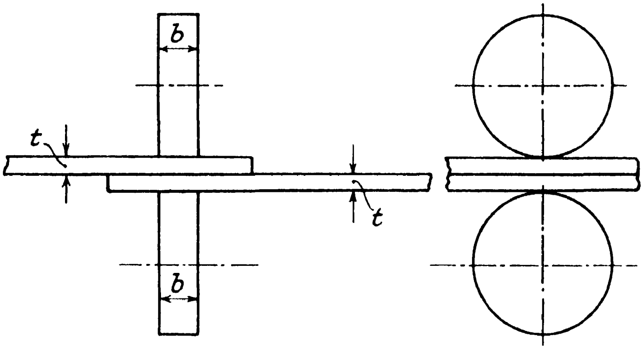
---

[1] Welding Memorandum No. 4c, Advisory Service on Welding, Ministry of Supply, London.

[2] Converted from: *Resistance Welding Manual*, published by the Resistance Welder Manufacturers' Association, Philadelphia Pa., U.S.A.

TABLE 20

Typical Settings for Seam Welding Low-Carbon Steel



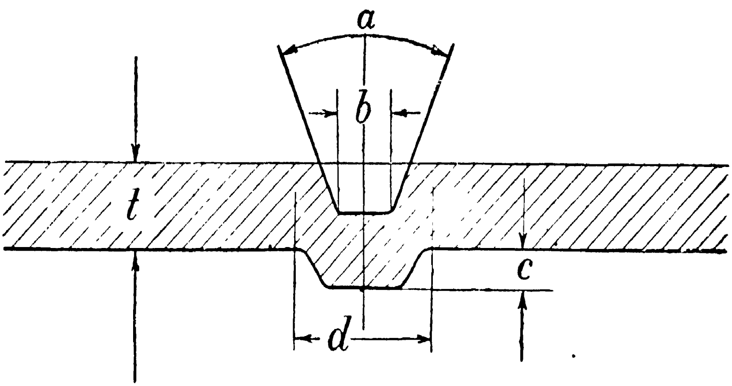
t		b	Circumferential speed of wheel	Welding current	Wheel pressure	Time	
						on	off
(S.W.G.)	(inches)	(inches)	inches/min.	(amps.)	(lb.)	(secs.)	(secs.)
20	0.036	0.16	96	15000	600	0.04	0.02
18	0.048	0.22	72	17600	750	0.04	0.04
16	0.064	0.25	72	20700	750	0.04	0.04
14	0.080	0.25	48	18600	900	0.07	0.07
10	0.104	0.28	48	20000	1000	0.08	0.07
12	0.128	0.30	24	20800	1200	0.10	0.10

Projection Welding allows more than one spot weld to be produced at a single operation, the number being determined by the number of projections between the plates. As all such welds are produced at the same time, the shunting effect between neighbouring welds is not detrimental (the current supply being sufficient for all welds) and the spacing between the spots is not critical as in the case of spot welding. The process may, therefore, be used where space limitations make it impossible to space spot welds in accordance with the above recommendation.

The tooling cost is, obviously, higher for projection than for spot welding, as the necessary projections have to be produced first. Table 21 shows typical projections as used on sheet material, and

TABLE 21

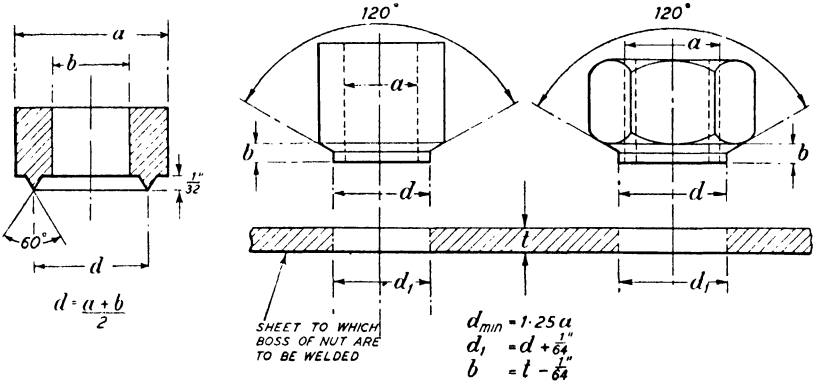
Typical Projections Used on Sheet Steel



t		a	b	c	d
min. (inches)	max. (inches)	(degrees)	(inches)	(inches)	(inches)
0·020	0·040	90	0·030	0·030	0·125
0·030	0·045	90	0·040	0·034	0·144
0·045	0·070	90	0·050	0·040	0·170
0·070	0·100	90	0·080	0·046	0·192
0·100	0·140	40	0·080	0·055	0·172
0·140	0·190	40	0·080	0·065	0·185
0·190	0·250	40	0·080	0·075	0·250

TABLE 22

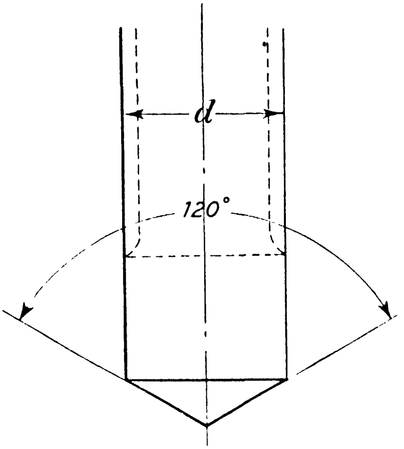
Recommended Settings for Projection Welding Low-Carbon Steel


a
b
1"/32
60°
d
d = (a + b)/2
120°
120°
a
a
b
b
d
d
t
d_1
d_1
SHEET TO WHICH BOSS OF NUT ARE TO BE WELDED
$d_{min} = 1{\cdot}25\,a$
$d_1 = d + \frac{1}{64}''$
$b = t - \frac{1}{64}''$

d (inches)	Welding current (amps.)	Welding pressure (lb.)	Welding time (secs.)
$\frac{1}{4}$	23000	1200	0·10
$\frac{5}{16}$	29000	1300	0·10
$\frac{3}{8}$	29000	1600	0·25
$\frac{7}{16}$	29000	1900	0·38
$\frac{1}{2}$	31500	2200	0·10
$\frac{9}{16}$	31500	2400	0·25
$\frac{5}{8}$	31500	2650	0·50
$\frac{11}{16}$	39500	2900	0·25
$\frac{3}{4}$	39500	3200	0·38

TABLE 23

Recommended Settings for Projection Welding Low-Carbon Steel Studs to Plates



d (inches)	Welding current (amps.)	Welding pressure (lb.)	Welding time (secs)
$\frac{1}{8}$	15500	180	0·1
$\frac{3}{16}$	18000	420	0·1
$\frac{1}{4}$	23000	750	0·1
$\frac{5}{16}$	29000	1160	0·1
$\frac{3}{8}$	31500	1650	0·1
$\frac{7}{16}$	31500	2250	0·2
$\frac{1}{2}$	39500	2950	0·1
$\frac{5}{8}$	45000	4500	0·1

Tables 22 and 23 show projections and settings for welding mild steel studs and bosses and hexagon nuts, respectively, to mild steel plates.

Due to the variety of conditions (plate thicknesses, projection shapes, bore diameter of bosses, etc.) no definite data for specific pressures and current densities are available, and the settings given in the tables are established empirically.

Flash Butt Welding is particularly useful in cases of large quantity production where large forgings can be replaced by smaller forgings welded to standard rolled sections. With some special precautions such as preheating, and heat treatment after welding, alloy steels can be welded satisfactorily. The shape and area of the two components must be identical at the point to be joined, and a suitable upset allowance must be made. (Fig. 4.11.)

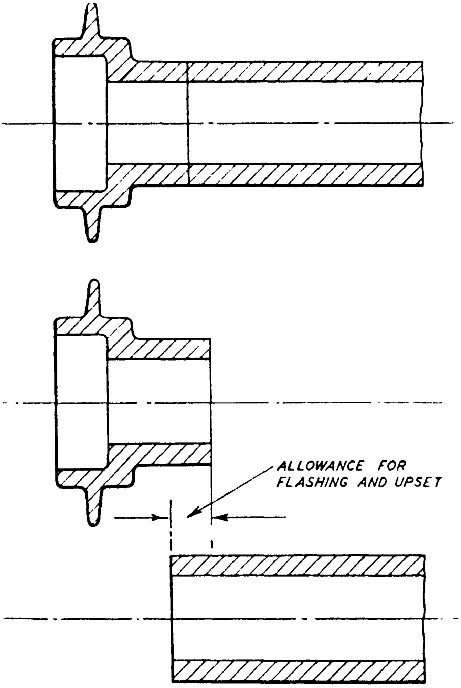


Fig. 4.11

Current densities vary considerably in flash butt welding, between 2000 and 25000 amps. per square inch welded area. The minimum value is determined by the requirements for obtaining stable flashing, the maximum value by the properties of the component material and the size and shape of the area to be welded.[1]

As an example, large areas to be welded require a low current density which results in a relatively slow rate of heating. In this way a larger zone behind the weld will reach the state of plasticity before the abutting ends are ready for welding, thus producing the conditions required for obtaining a good upset.

---

[1] See J. S. Blair, "Production of High Quality Flash Butt Welds," *Transactions of the Institute of Welding*, August 1947.

Due to the great variety of shapes and sizes which can be flash butt welded, there is no point in giving typical settings. These have to be found experimentally for each particular job.[1]

Special Devices. The foregoing descriptions of resistance welding processes deal with standard procedures and equipments. Many departures from these standards have often been used to increase the scope and efficiency of the processes.

In spot welding the use of two electrodes (one on either side of the plates to be welded) (Fig. 4.12,*a*) is sometimes replaced by the use of one electrode and one platen (Fig. 4.12,*b*). Whilst the electrode tip on the top side determines the current density and the weld diameter, the platen at the bottom side prevents indentation and marking, and results in a better appearance of the outer surface of the bottom plate. The idea can be applied for multi-spot welding (Fig. 4.12,*c*) where several transformers feed one common platen specially shaped to suit the component, whilst each transformer supplies its own top electrode (see Fig. 4.17).

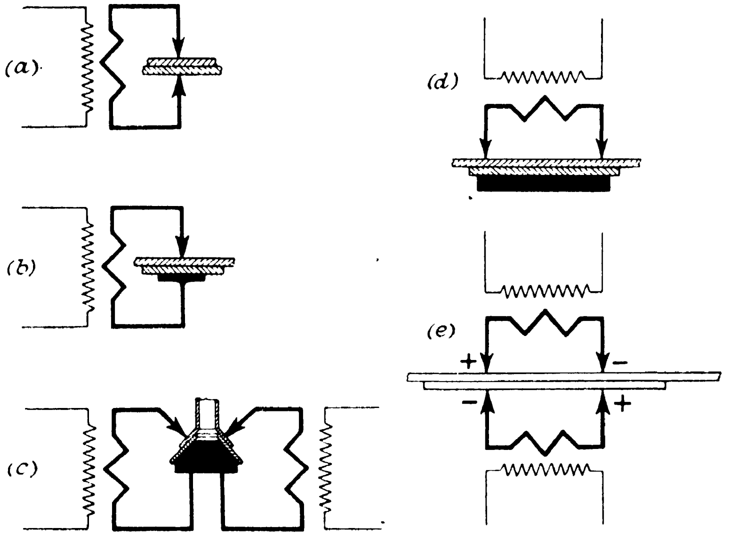


Fig. 4.12

In cases where the overall size of the plates to be welded is too large to fit into the throat of the spot-welding machine, the arrangement (Fig. 4.12,*d*) has been used. The transformer feeds the two top electrodes, and the plates are supported by a loose platen which is not directly connected to the transformer. The current has to travel from one electrode, through both plates at the first welding point, through the bottom platen, and back through the plates at the second welding point to the second electrode.

---

[1] See, for example, D. B. Johnston, "Flash Welding of Concentrated Areas up to 24 sq. in. in SAE 1020, NE 9440, and NE 8620 Steels," Welding Research Supplement, *Welding Journal*, February 1947.

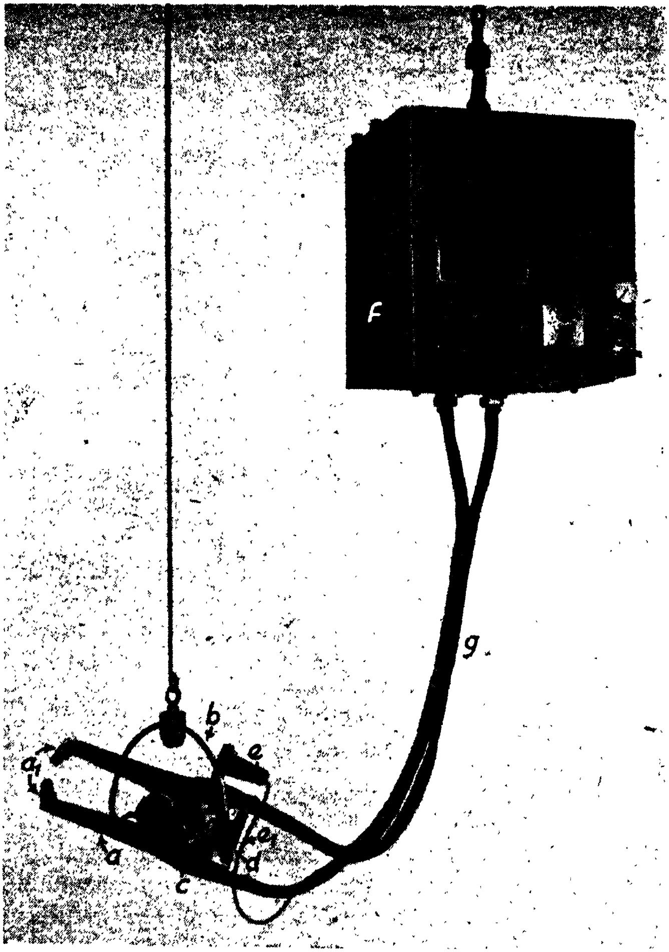


Fig. 4.13. Portable Spot Welder (*Sciaky*)

In this case it has to be considered that part of the current will return through the plates directly without going through the bottom platen and without being used for welding, the amount depending upon the ratio between the resistance in the plates between the two electrodes on the one hand and the resistance of twice the plate thicknesses plus that of the bottom platen on the other hand. As the platen is of a material similar to that of the electrode and its conductivity much higher than that of the steel plates to be welded, most of the current will be available for welding, the percentage being the greater the larger the spacing between the electrodes. The problem can be eased by using two sets of transformers, one on either side of the plates to be welded (Fig. 4.12,*e*).

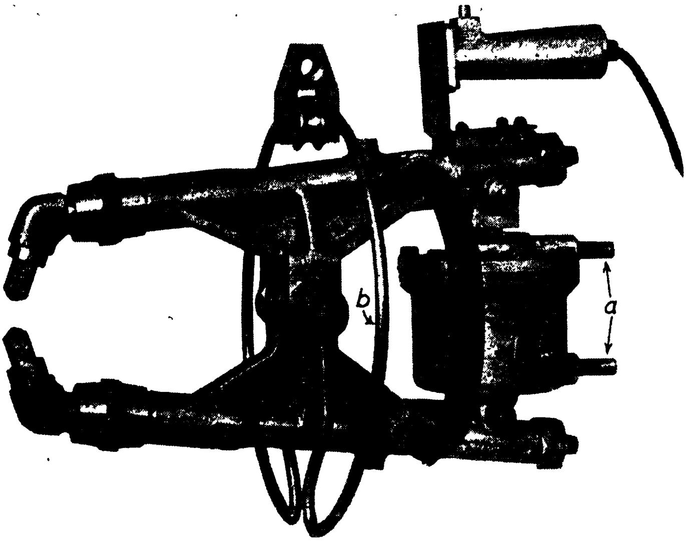


Fig. 4.14. Portable Spot Welding Pliers (*Sciaky*)

For carrying out spot welding operations on components which are too large to be handled in the usual way, *portable spot welding sets* are being used (Fig. 4.13). They consist of the spot welding pliers *a*, (electrodes a_1), which are usually suspended from a jib crane and hanging on a ring-type carrier *b* for easy manoeuvering. Welding pressure is exerted by pneumatic cylinder *c*, whilst springs *d* open the pliers after the air pressure is cut off. Hand switch *e* (cable e_1) initiates the welding cycle which is controlled by the equipment in cabinet *f*. Cabinet *f* also contains the welding transformer. Current and cooling water are supplied through hose pipes *g*, the cooling water being also used to cool the cable conductors inside the hose pipes, whose current-carrying cross section is on the small side in view of the need for flexibility.

Different types of *welding pliers* have been developed. Those in Fig. 4.14 are of a similar type to those in Fig. 4.13, but here the opening of the pliers is not effected by springs but by compressed air (*a*), while the suspension ring (*b*) allows for nearly 360° rotation.

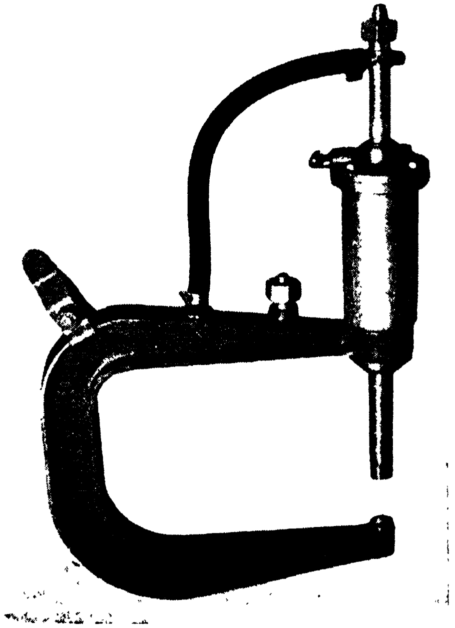


Fig. 4.15. Portable Spot Welding
(*Sciaky*)

In the *C-shaped welding frame* (Fig. 4.15) the pneumatic cylinder exerts the pressure directly on the electrode holder, thus excluding hinged parts as used in the previous two types.

For *mass production of small components*, spot and projection welding machines for single operation but with rotating tables operated by indexing mechanisms have proved efficient.[1] Special clamping fixtures (*a*, Fig. 4.16) to suit the particular components, are fitted to the indexing table *b* which brings them in rotation under the electrode head *c* for the welding operation. After the welding operation, the components are ejected by means of cam *d* and ejection levers *e* as, e.g. shown in position *f*. Pneumatic operation or Geneva wheel motion is used for the indexing mechanism.[1]

---

[1] See W. A. Knipe, "Multiple Resistance Welding," *Machinery*, February 7th and 14th, 1946.

The *single purpose six-point spot welding machine* is equipped with six separate pneumatic cylinders *a* each operating one of the top electrodes *b* against one common bottom electrode *c* (Fig. 4.17). Three power transformers supply the welding current (see Fig. 4.12,*c*), and electronic timing with ignitron primary current control is used. This machine has a normal capacity of 100 k.v.a.

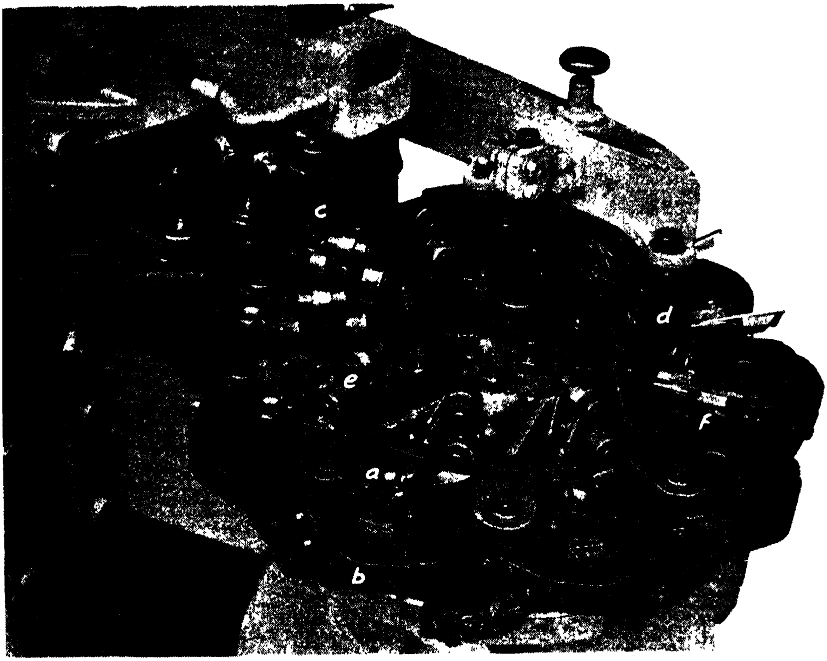


Fig. 4.16. Automatic Spot Welder with Indexing Head (*Sciaky*)

Flash-butt welding machines cannot follow in general design more or less standard lines, like spot and projection welding machines. The variety in shape and size of the components considerably influences their general lay-out.

The general purpose flash butt welder (Fig. 4.18), for welding up to a maximum cross sectional area of 6 square inches in mild steel, is equipped with a single phase water-cooled transformer of 250 k.v.a.

---

[1] See W. A. Knipe, "Multiple Resistance Welding," *Machinery*, February 7th and 14th ,1946.

rated capacity. Water is also used for cooling the electrode blocks and clamping dies a_1,a_2. These are operated by means of pneumatic cylinders *b* (air pressure 80–100 lb. per square inch) through levers *c*. The left-hand clamping head a_1 is rigidly clamped to, but insulated from the machine frame, whilst the right-hand clamping head a_2 can slide towards the left-hand one, this motion being either operated automatically by means of compressed air and a mechanical lever arrangement, or by the handwheel *d*. The latter provision is made for giving specially long preheating times by repeatedly reciprocating the head, when welding the heavier sections. After such preheating the actual upsetting and welding is always controlled automatically by the control gear which has to be set for the particular job. The *automatic flash butt welder* (Fig. 4.19) of 250 k.v.a. rated capacity

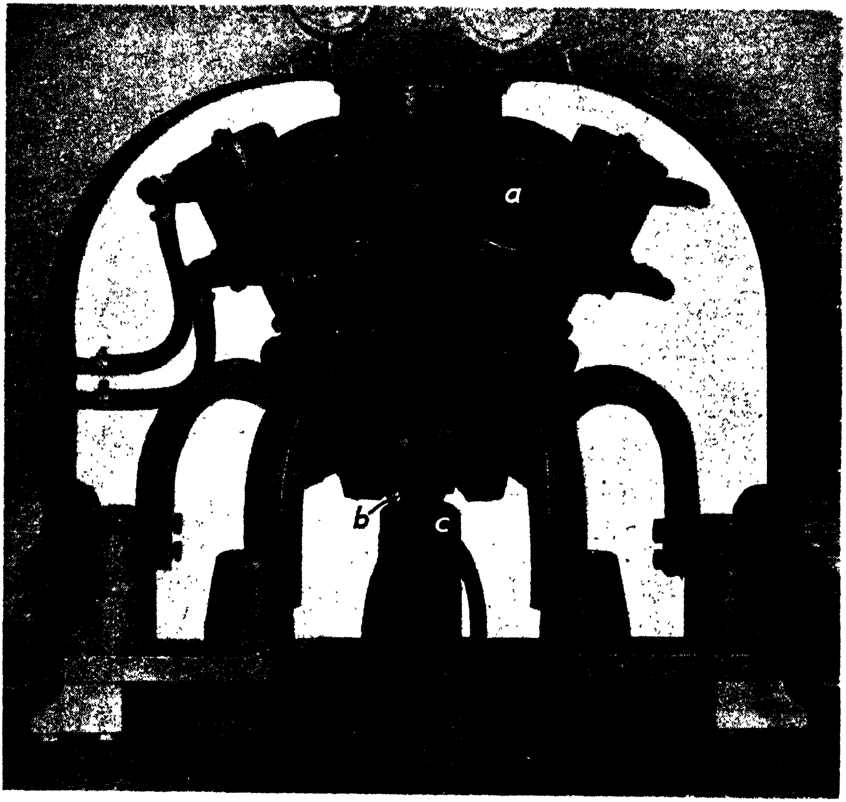


Fig. 4.17. Multiple Spot Welding Head (*Sciaky*)

is designed for the welding of pipes and flanges (an example lies in front of the machine), and the hinged clamps are arranged to suit.

An interesting application of flash butt welding is shown by the 200 k.v.a. high speed automatic flash butt welder (Fig. 4.20) which serves for closing heavy section rims made from rolled sheet material. The welding current required for such cases is higher than usual, due to the shunting effect of the closed side of the rolled ring.

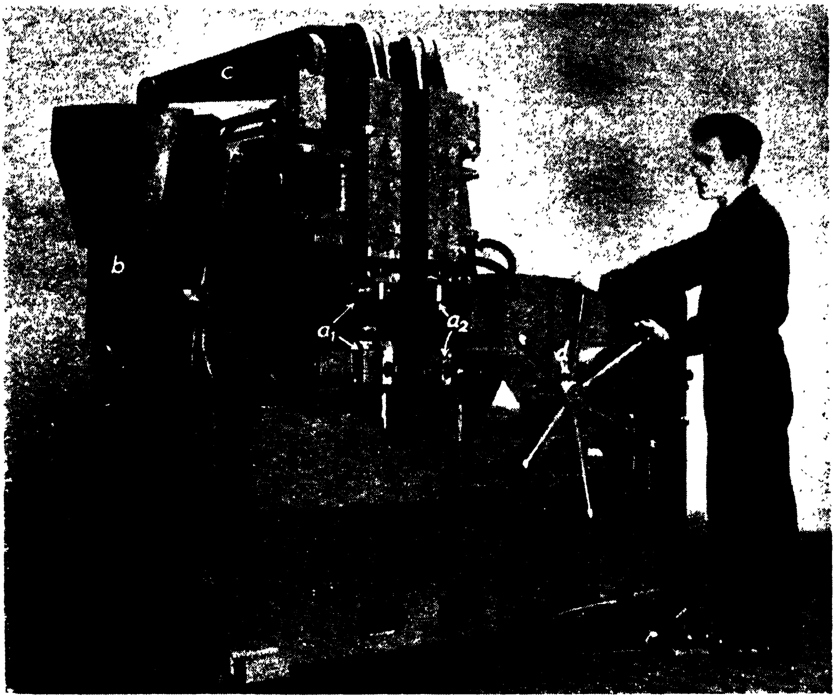


Fig. 4.18. General Purpose 250 k.v.a. Flash Butt Welder (*A.1 Electric*)

Testing. Resistance welded joints can usually only be checked by destructive tests, and it is more or less standard practice, prior to putting a batch of components through production, to break a typical test-piece. It is especially important that the material of the test piece is identical with that of the actual component, and that the welding settings and the amount of metal in the throat of the welding machine are the same as occuring on the actual job in question. The necessity for the preparation and breaking of test pieces periodically during production and the need for close control over the quality and state of tools, working material, and components, are reasons for resistance welding being most economical when used for quantity production.

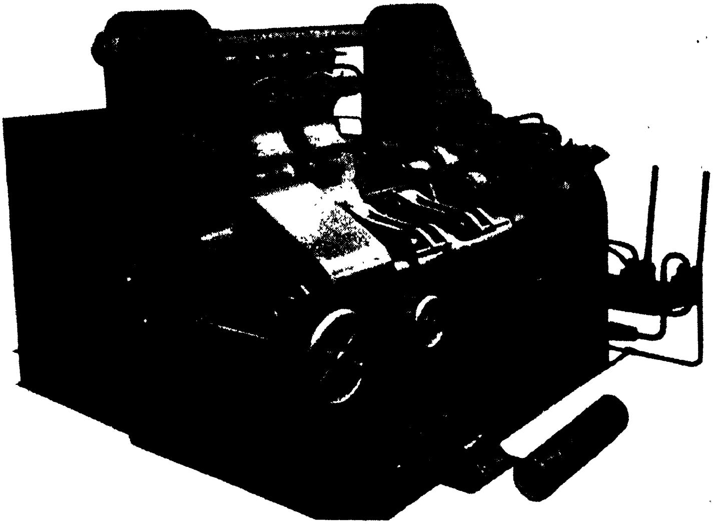


Fig. 4.19. 250 k.v.a. Automatic Flash Butt Welder (pipes and flanges) (*A.1 Electric*)

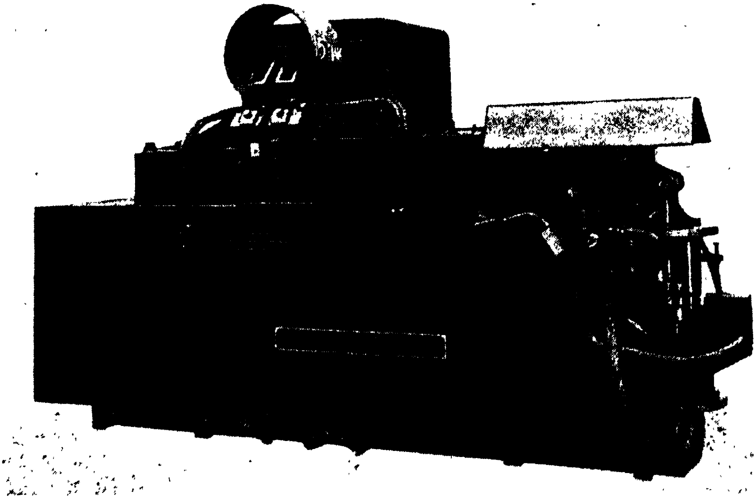


Fig. 4.20. 200 k.v.a. High Speed Automatic Flash Butt Welder (heavy section rims) (*A.1 Electric*)

CHAPTER V

WELDING FERROUS METALS

Weldability. The various welding processes often affect the properties of the materials involved. The high temperatures cause chemical changes through interaction with surrounding gases, and metallurgical changes may take place due to the heating and the subsequent cooling rate. If such changes are likely to be detrimental to the finished work, precautions have to be taken, and a material is considered the more "weldable" the fewer such precautions are required.

L. Reeve[1] has defined *weldability* as "a combined property of base metal and filler metal or electrode, the measure of which is the capacity to produce crack-free and mechanically satisfactory welded joints, by as many as possible of the known welding processes."[2]

Among the chemical and physical changes which may affect the mechanical soundness of a welded joint are oxidation resulting in blow holes or slag inclusions; attraction or loss of an element in gaseous form causing porosity; and absorption of hydrogen causing embrittlement.[3] Physical loss of an alloying element may occur if its temperature of vaporization is below the melting point of the parent material, and may influence the mechanical properties of the finished article. Those dangers can usually be avoided by employing suitable electrode material; by using fluxes to protect the welded zone; by introducing protecting gases from a separate source (argon-arc welding); or by producing protecting gases from suitable electrode coatings which are gasified by the welding heat.[4]

The main problem in connection with weldability seems, however, to be the development of cracks either in the weld itself, or in the junction zone between the weld and the parent material or in the parent metal adjacent to the weld. If the material is not sufficiently ductile to withstand the strain created by expansion and contraction due to heating, cracking may occur, as the yield point value of the material may be near its ultimate strength value.

---

[1] "Factors Controlling the Weldability of Steel," *Welding*, November and December, 1944.

[2] See also: W. L. Warner, "This Elusive Character Called Weldability," Welding Research Supplement, *Welding Journal*, March 1946, and G. G. Luther, C. E. Jackson, and C. E. Hartbower, "A Review and Summary of Weldability Testing Carbon and Low Alloy Steels," Welding Research Supplement, *Welding Journal*, April 1947.

[3] See A. E. Flanigan, "An Investigation of the Influence of Hydrogen on the Ductility of Arc Welds in Mild Steel," Welding Research Supplement, *Welding Journal*, April 1947.

[4] See W. Andrews, "Construction of Weld Metal," *Transactions of the Institute of Welding* August 1945.

The metallurgical structure and—as explained—the ductility of steel may be affected by the welding process,[1] because welding temperatures are above the upper critical point and, unless special precautions are taken, cooling rates are comparatively high due to the quenching effect of the cold material adjacent to the welded zone. If a very high cooling rate could be obtained, no time would be given to the material to change its structure. It would then maintain at room temperature the austenitic structure, (solid solution of carbon in iron), formed above the upper critical point (see Fig. 5.1), with its high ductility.

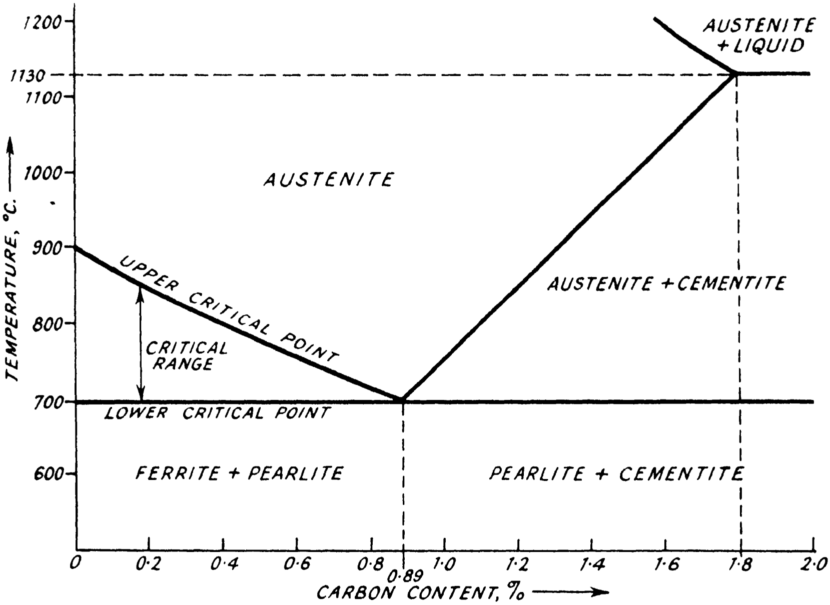


Fig. 5.1

With ordinary carbon steels sufficiently high cooling speeds cannot be obtained, and the austenite cannot be preserved. The normal cooling rates after welding are, however, too high to allow the material to change back to its original structure containing pearlite,[1] and through iron carbides being trapped in the form of a supersaturated solution of carbide in ferrite, martensite will be formed. As this is a very hard crystalline structure, it increases the hardness and reduces the ductility of the material.

---

[1] See Progress Reports Nos. 1 and 3, "Effect of Metallurgical Changes due to Welding upon the Fatigue Strength of Carbon Steel Plates," Welding Research Supplement, *Welding Journal*, August 1946.

The lower the carbon content of steel, i.e. the higher the percentage of free iron (ferrite), the weaker in carbon will be the austenite, resulting in a lower percentage of martensite in the steel after quenching.

On the other hand, the higher the carbon content, the smaller the critical range for redeveloping the pearlitic structure (see Fig. 5.1) and the greater the danger of obtaining a martensitic structure after welding.

It is not intended to discuss these metallurgical problems to any great extent, but in order to show the relation of carbon content, metallurgical transformation, and temperatures, the schematic graph (Fig. 5.1) is included. More detailed information on the subject can be found in various text-books on metallurgy, and in publications on the particular problems connected with welding.[2]

From the foregoing it will be clear that the rate of cooling, which produces the quenching effect, is of great importance, and that the composition of parent and filler material, particularly the carbon content, determines the influence of this quenching effect on the ductility in the welded zone.

To estimate the effect of the quenching action exerted by the parent material, it must be remembered that with thick plates the zones round the weld heat up more slowly and cool down more quickly after welding than with thin ones. Due to the mass of metal in a thick plate only a small portion of parent material, that directly adjacent to the weld, will be heated up to the welding temperature; and due to the large heat-conducting section this heat will be dissipated rapidly after the application of heat has ceased.

When welding larger sections the greater heat input obtained by using larger blowpipe nozzles in gas welding (see pages 14–15) or by employing higher welding currents in case of arc welding (see page 47) serves not only for faster heating of the materials to be welded but also for reducing their cooling rate. The same purpose is served by keeping fillet welds above certain minimum sizes in relation to the thickness of the plates to be joined (see page 46).

---

[1] Pearlite consists of 13 per cent cementite (Fe_3C) and 87 per cent ferrite (Fe).

[2] See R. H. Aborn, " Metallurgical Changes at Welded Joints and the Weldability of Steels," *Welding Journal,* October 1940. H. O'Neill, " Metallurgical Features in Welded Steels," *Transactions of the Institute of Welding,* February 1946. B. Ronay, " A Method of Determining the Applicable Welding Procedure for Steels," Welding Research Supplement, *Welding Journal,* November 1946.

The ductility of the weld and the material adjacent to it is of the greatest importance when distortion occurs and stresses are caused by the welding heat. The ductility of low carbon steels (up to a maximum of 0·25 per cent C) after welding is usually high enough and their yield point well below the ultimate strength, so that the weld will yield sufficiently to withstand the strain caused by heat expansions and contractions, without cracking. If, however, two plates of greatly different thicknesses are welded together, the different rates of heating and cooling may put too heavy a strain on the connecting weld, and cracking may occur. Such difficulty can be overcome by suitably preheating the larger mass of material, thus equalizing the amount of contraction in the various parts of the structure during the cooling period after welding.

In Chapters II to IV typical settings have been shown for welding mild (low carbon) steel which, due to the good ductility after welding (see page 105), has good weldability by all welding processes. The problem becomes more difficult when other steels have to be welded. The following may be quoted from the Memorandum on the *Arc Welding of High Tensile (Low Alloy) Structural Steels.*[1]

"The weldability of a high tensile steel decreases with an increase in the percentage of carbon and other alloying elements which it contains, the effect of carbon being the most important, and far greater than that of the other elements. The greater the amount of carbon, manganese, nickel, chromium, molybdenum, copper, and other elements present in the steel, the harder will the weld junction tend to become and the greater will be the tendency for the formation of cracks in the hardened zone."

The relation between the influence of carbon and that of other alloying elements upon the weldability of steel has been investigated by Dearden and O'Neill,[2] and the following formula for the "carbon equivalent" of alloying elements has been established:

$$C_e = C + \frac{Mn}{6} + \frac{Cr}{5} + \frac{Ni}{15} + \frac{Mo}{4} + \left(\frac{Cu}{13} + \frac{P}{2}\right),$$

where C_e is the "carbon equivalent" in per cent, and C, Mn, Cr, Ni, Mo, Cu, and P are the percentages of carbon, manganese, chromium, nickel, molybdenum, copper, and phosphorus contents respectively, the factor for copper and phosphorus being applied only when their percentages exceed ·05 per cent each.[1]

---

[1] Report T 2, issued by the Welding Research Council of the Institute of Welding, February 1944.

[2] Dearden and O'Neill, "A Guide to the Selection and Welding of Low Alloy Structural Steels," *Transactions of the Institute of Welding*, October 1940, p. 203.

For various cases of carbon and low alloy steels a maximum carbon equivalent can be determined, below which no cracking is likely to occur with the ordinary welding procedure. If this carbon equivalent is exceeded, special precautions have to be taken.

Suitable welding procedure and heat treatment of the welded parts (preheating, postheating, normalizing) will often give the desired result, but the use of special filler material may sometimes be necessary.[2] In the case of arc welding electrodes it is not only the filler material but also the electrode coating that influences the quality of the weld (see page 39), and a great variety of arc welding electrodes has been developed to suit the various welding problems which may be encountered (see page 40).

High Tensile Steels. Preheating (300–400°C.) to reduce the cooling rate, and heat treatment after welding (650–750°C.) to reduce hardness and restore ductility, are recommended for the welding of medium carbon steels (up to 0·45 per cent C) and high tensile low alloy steels. With this precaution these steels are readily weldable by the oxy-acetylene, electric-arc, and resistance welding processes.

In the case of resistance welding, high carbon content may again result in a hardening effect producing hard and brittle welds. To overcome this difficulty low current settings and long welding times may reduce the quenching effect. Long welding times, however, reduce the life of spot welding electrodes, and it is preferable[3] to apply a second current impulse when the job has cooled down after welding, and while it is still between the spot welding electrodes. In his paper[3] Gardner draws attention to the fact that this technique, which requires special control gear on the spot welding machine, cannot generally be used for projection welding processes.

---

[1] See also L. Reeve, " Influence of Sulphur and Phosphorus on Weldability of Mild Steel," *Transactions of the Institute of Welding*, May 1945.

[2] See D. Hanson, A. H. Cottrell, K. Winterton, J. A. Wheeler, and P. D. Crowther, " Researches in Alloy Steel Welding," *Transactions of the Institute of Welding*, July 1944.

[3] H. St. G. Gardner, " System of Indicating Welding Requirements on Engineering Drawings," *Transactions of the Institute of Welding*, February 1945.

TABLE 24

Recommended Conditions for Spot Welding High Tensile Carbon and Low-Alloy Steels[1]

Composition of Material								Thickness of each plate t	Electrode Limiting diameter	Electrode Dome radius	Welding current	Tempering current	Electrode pressure	Welding time	Cooling time	Tempering time
C	Mn	P	S	Si	Ni	Cr	Mo									
%	%	%	%	%	%	%	%	(inches)	(inches)	(inches)	(amps.)	(amps.)	(lb.)	(secs.)	(secs.)	(secs.)
0.155	0.82	0.017	0.030	0.25	0.51	0.46	0.20	0.018	0.125	6	3900	3400	350	0.05	0.07	0.05
								0.062	0.3125	6	12250	10000	1600	0.17	0.47	0.17
								0.125	0.625	10	22700	20000	4500	0.75	3.00	1.50
0.30	0.50	0.016	0.028	0.25	—	0.96	0.19	0.040	0.25	6	13000	12000	1475	0.10	0.30	0.10
0.30	0.83	0.017	0.020	0.24	0.53	0.52	0.21	0.031	0.1875	6	8650	7500	800	0.07	0.20	0.07
								0.062	0.3125	6	12800	10500	1800	0.17	0.60	0.17
								0.125	0.625	10	21800	19000	4500	0.75	3.50	1.50
0.40	0.72	0.019	0.018	0.24	1.78	0.88	0.22	0.031	0.1875	6	8250	7000	900	0.07	0.20	0.07
								0.062	0.3125	6	13900	10500	2000	0.17	0.75	0.17
								0.125	0.625	10	21800	19000	5500	0.75	4.00	1.50
0.48	0.79	0.009	0.022	—	—	—	—	0.040	0.25	6	13800	12000	1475	0.10	0.25	0.10

---

[1] A .W. D. Doty and W. J. Childs, *Welding Research Supplement. Welding Journal,* October 1946.

The optimum conditions for spot welding high tensile carbon and low alloy steels have been investigated[1] for the spot welding of sheets up to 0·125″ thickness with the following results:

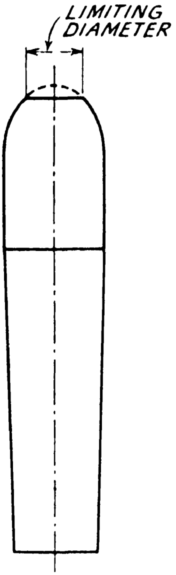


Fig. 5.2

Dome-shaped electrodes (Fig. 5.2) are recommended, and optimum electrode sizes, welding pressures, and welding times are as shown in Table 24. After the actual welding operation the welding current is cut off, but the components are held between the electrodes and the welds are allowed to cool down. After a predetermined cooling time the above-mentioned second current impulse is applied, which anneals the structure resulting from the original welding operation. In this way a tough and ductile weld is obtained. Cooling and tempering times and tempering currents are also shown on the table. For accurate timing, the whole cycle is electronically controlled (see page 166).

For arc welding high tensile or chromium and similar alloy steels, particularly if annealing after welding presents difficulties, the austenitic condition of the filler metal created during the welding process can be maintained at room temperature by using filler rod materials which contains certain alloying elements, particularly chromium and nickel ("austenitic electrodes"). The result is a highly ductile material in the finished weld.

Austenitic nickel-chromium filler material has been found to absorb carbon from the heat-affected zone of the parent metal adjacent to the weld, a fact which has proved of importance in the welding of alloy steel piping used for high temperature service.[2]

Stainless Steels.[3] Amongst the stainless steels at present available, the 1272 variety (12 per cent chromium and 2 per cent nickel) has a relatively high carbon content (sometimes 0·3 per cent and above), and will be easily hardened. Preheating (at least to 400°C.) to slow down the cooling rate, and tempering (650–700°C.) after welding is necessary, especially if the product is likely to be subjected to shock loads. The filler rod material should be in accordance with the composition of the parent metal.

---

[1] A. W. D. Doty and W. J. Childs, "Summary of the Spot Welding of High Tensile Carbon and Low Alloy Steels," Welding Research Supplement, *Welding Journal,* October 1946.

[2] I. A. Rohrig, "A Study of Austenitic Welding for Control of Graphitization in Steel," Welding Research Supplement, *Welding Journal,* February 1946.

[3] See L. K. Stringham, "Correct Technique Necessary for Stainless Welding," *The Iron Age,* August 21st, 1947.

The 18/8 variety (18 per cent chromium and 8 per cent nickel) is an austenitic steel and, therefore, of good weldability. The following points are, however, of importance if the material is to retain its properties. Oxidation must be prevented, and when *oxy-acetylene welding* stainless steel, a very slight acetylene surplus in the blowpipe flame is sometimes recommended[1] to avoid the risk of having an oxidizing flame, although carburization produces brittle welds.

The filler rod is usually fluxed before the operation, for protection of the weld. When welding square butt joints from one side only, flux has to be applied to the underside of the plate.

The heat conductivity of stainless steel is only about 50 per cent of that of mild steel. The heat convection in the material is, therefore, reduced, and it is recommended to use a slightly smaller nozzle size in the oxy-acetylene blowpipe than would be used for the same thickness of mild steel (see page 14). In all fusion welding processes weaving motion of the filler rod is to be avoided, as it would help the formation of oxide inclusions.

The flux-coating of electrodes used for *metal-arc welding* stainless steel contains the elements which are likely to be evaporated in the arc during welding, in order to replace them and to obtain a weld metal whose composition is equal to that of the parent material. Careful cleaning of the edges to be welded and slag removal after each run are essential for obtaining a good quality weld. Weld settings are given by the electrode manufacturers to suit their particular types of electrodes.

Argon-arc welding of stainless steel can be carried out with A.C. or D.C. supply, A.C. being slightly superior because of the lack of arc blow. Welding in a draughty atmosphere should be avoided, as air-draughts might disturb the argon shroud around the arc, thus destroying the protection against oxidization. Table 25[2] shows recommended weld settings.

The *atomic hydrogen process* is particularly useful for welding stainless steels, not only because the hydrogen shroud protects the weld generally but also because of the reducing effect of hydrogen. This prevents oxidization without the danger of carburization. For protective purposes a slight stream of hydrogen is sometimes diverted to the underside of square butt joints which are welded from one side

---

[1] *B.O.C. Handbook for Oxy-Acetylene Welders.*

[2] *B.O.C. Instruction Manual for Argon-Arc Welding.*

TABLE 25

Argon-arc Welding of Stainless Steel[1]

Material thickness S.W.G.	Tungsten electrode dia. (in.)	Filler rod dia. (in.)	Approximate welding current (amps.)	Argon consumption Litres/min.	Edge preparation
20	$\frac{3}{32}$ to $\frac{1}{8}$	$\frac{1}{16}$	30–40	1	Close butt, square edge, or close butt, formed edge.
18	$\frac{3}{32}$ to $\frac{1}{8}$	$\frac{1}{16}$	40–50	1	Close butt, square edge.
16	$\frac{1}{8}$ to $\frac{3}{16}$	$\frac{1}{16}$ to $\frac{3}{32}$	60–80	1·5	Close butt, square edge.
10	$\frac{3}{16}$	$\frac{1}{16}$ to $\frac{3}{32}$	80–120	2	Close butt, square edge.
10	$\frac{3}{16}$	$\frac{3}{32}$ to $\frac{1}{8}$	80–120	2	$\frac{t}{3}$ gap, where $t =$ thickness of material

NOTE. When Direct Current is used, the electrode must be connected to the negative terminal of the generator, and the electrode must be ground to a sharp point.
These figures are for guidance only.

[1] British Oxygen Co., Ltd.

only.[2] The use of less expensive gases for the same purpose has not proved equally effective.

Resistance welding can be carried out successfully on stainless steels provided overheating is avoided by keeping the welding times short.

In spite of the good weldability of austenitic stainless steels, their corrosion resistance may be affected by welding, for the following reason. When heated for a certain time between 500–900°C. and allowed to cool normally, chromium-carbide precipitation occurs in the crystal boundaries which become more liable to corrosion than the remaining material, causing the crystals to fall apart some time afterwards. As this phenomenon is always occurring near welds, it is called "weld decay", although it only occurs in a zone at a short distance from the weld, which has cooled down at a slower rate than the weld itself.

---

[2] G. Richardson, " Atomic Hydrogen Welding of Stainless Steel," *The Iron Age*, May 8th, 1947.

Heat treatment by heating above 1100°C. and cooling rapidly in an air blast will not give the chromium carbides time to migrate to the crystal boundaries and will prevent the above trouble. The need for this heat treatment can be avoided, however, and a more "weldable" stainless steel produced by adding certain elements which prevent the carbide precipitation. Columbium (up to 2·5 per cent), titanium (up to 0·8 per cent), tungsten (up to 0·8 per cent), or molybdenum (up to 4 per cent) are used by various steel makers, each having its particular advantages.[1]

Cast Steel. Good quality cast steels with a carbon content below 0·25 per cent can usually be welded in the same way as ordinary mild steel. With higher carbon content or alloy cast steels preheating (bright red) and sometimes stress-relieving or annealing after welding are necessary. Special electrodes are often recommended by manufacturers.

Cast Iron.[2] Iron with a carbon content above 1·8 per cent does not pass through a plastic state during heating, but changes immediately from the solid into the molten state. It cannot be forged, therefore, but it can be cast and fusion-welded.

In the molten state cementite (iron carbide) is found in solution in the ferrite (iron). When cooling down rapidly the carbon in excess of that held in the pearlitic structure is found as cementite (see Fig. 5.1), forming a very hard and brittle material (white cast iron), whilst, by cooling slowly, the carbon becomes free in the form of graphite flakes, and the result is a machineable material of good mechanical properties (grey cast iron).

The former material is mainly used for very hard wearing surfaces and—by applying appropriate heat treatment—for producing malleable cast iron. By special treatment and addition of various elements alloy cast irons have also been produced which have either high tensile properties (e.g. Meehanite) or high heat or corrosion resistance.

In welding grey cast iron, as its ductility is low, fractures are likely to occur due to the stresses created by local heating. If the cooling rate is high, transformation of the heat-affected zone into brittle white cast iron will occur. Carbon may be transferred from the molten parent metal into the weld, making the latter very hard and brittle. Local preheating and slow cooling can overcome these difficulties. A preheating temperature of 600°C. is recommended, and it is important that the full thickness to be welded is brought up to and kept at this temperature throughout the welding operation.

---

[1] See *Murex Handbook for Electric Welders.*

[2] See J. G. Pearce, "The Welding of Cast Iron: A Review," *Transactions of the Institute of Welding,* October 1942.

If a structure is restrained from expanding and contracting near the welded portion, indirect preheating at the restraining portion will provide thermal expansion in parallel with the welded part, thus preventing stresses which might cause cracking. A temperature of 200°C. is sufficient for this purpose. Fig. 5.3[1] shows the application of direct and indirect preheat when welding up a crack in a casting. Only in the case of very complicated castings may it be necessary to preheat the whole structure in a specially arranged furnace.

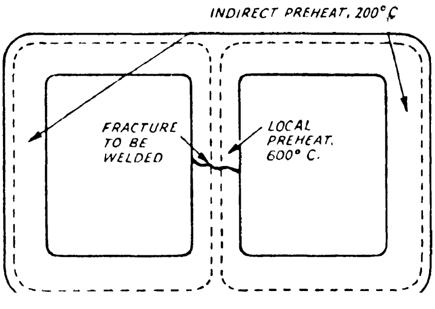


Fig. 5.3

To obtain sound welds good edge preparation is particularly essential, consisting in suitably bevelling the edges to be welded and carefully cleaning the faces to be welded from dust, sand, grit, oil and grease.

When *oxy-acetylene welding* cast iron a neutral flame should be employed. Care should be taken to prevent the inner cone of the flame from coming into contact with the molten metal, as otherwise carbon might be taken up, causing the weld to be hard and brittle. Cast iron filler rods are used, and the use of a flux is recommended,[2] in order to prevent oxidization and to assist the flow of molten metal and the removal of the heavy oxides present in the metal.

Carbon-arc welding can be used in a way similar to oxy-acetylene welding.

---

[1] *Murex Handbook for Electric Welders.*

[2] *B.O.C. Handbook for Oxy-acetylene Welders.*

Special electrodes have been developed for *metal-arc welding* cast iron. As a weld metal deposit with a carbon content similar to that of the parent material is difficult to obtain—the carbon would burn out at the high temperature of the arc—nickel alloy electrodes are often recommended. The weld metal deposited with these electrodes will not easily take carbon out of the parent material, thus avoiding the formation of hard and brittle weld metal. Cast iron electrodes are covered with a suitable flux. Detailed operating instructions and weld settings should be obtained from the electrode manufacturers.

If large gaps have to be filled by welding, a first layer should be built up with copper nickel alloy electrodes on the cast iron edges, and the weld should then be completed with soft iron electrodes (Fig. 5.4).[1]

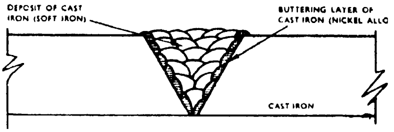

DEPOSIT OF CAST IRON (SOFT IRON)
BUTTERING LAYER OF CAST IRON (NICKEL ALLO
CAST IRON

Fig. 5.4 (*Murex*)

Thermit welding of cast iron has been successfully carried out for repair work. Some difficulty was originally encountered, due to normal thermit weld metal contracting more on cooling than cast iron, and cracks being caused in the weld. The use of a special cast iron thermit metal, consisting of a mixture of ordinary thermit material with ferro-silicon and mild steel punchings, overcomes this difficulty.

Malleable iron may lose its properties due to the heating and the subsequent rapid cooling, and may change back to the hardness and brittleness of white cast iron. Tensile strength and elongation approaching 90 per cent of the values in the parent material prior to welding, can be obtained by re-annealing after welding.

If this is not possible, a process which uses a lower welding temperature has to be employed and *bronze welding* has been found satisfactory for the purpose. This process lies in between brazing and fusion welding. The edges of the parent material are heated up to the melting temperatures of the welding rod (60/40 brass with some tin and silicon added as deoxidizers). In the case of cast and malleable iron, the bronze filler rod should have a lower melting point than the parent material to be welded.

As the temperatures employed are low in comparison with ordinary welding, thermal stresses and the resulting danger of cracks are considerably reduced. The strength of the joint depends on the shear strength of the amalgam at the junction, and no strength can be gained by building up large quantities of weld metal.

For preparing the operation the edges to be welded are bevelled

---

[1] *Murex Handbook for Electric Welders.*

(included angle about 90°) and well cleaned. Particular care has to be taken to remove graphite from the surfaces. For large castings preheating to about 400°C. is recommended. Correct preheating temperature of the parent material is essential, because if too cool the bronze will not spread satisfactorily, whilst if too hot it will form little balls which roll about under the blowing force of the oxy-acetylene flame. Flux is applied by heating the bronze filler rod and dipping it into the flux powder prior to welding. Manganese bronze or nickel bronze rods are used and a bond strength up to 25 tons per square inch has been obtained.[1]

Electric-arc bronze welding is also employed for repairing castings. A further application for bronze welding is the joining of two dissimilar materials, as long as their melting temperature is above that of the welding rod material, and amalgamation can take place between the welding rod and the parent materials to be welded.

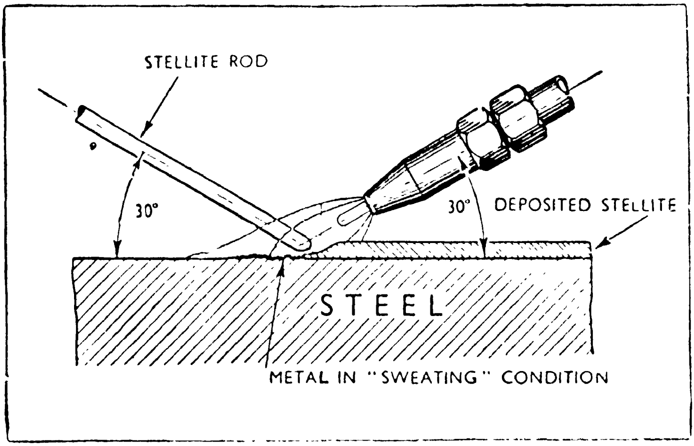


Fig. 5.5 *(B.O.C.)*

Hard facing.[2] A special application of the welding processes is the hard facing of wearing surfaces or cutting edges of tools.

Stellite, a mixture of tungsten and other carbides carried in a matrix of cobalt and deposited by means of the oxy-acetylene process (Fig. 5.5)[1] retains its high wear and corrosion resistance even at high temperatures. As its thermal contraction after deposition is higher than that of steel, preheating of the base material and slow cooling after completion of the operation are required to prevent cracking. For the same reason great lengths of stellite should not be deposited in one continuous run, but should be broken into short lengths, the stellite being deposited to alternate parts.

---

[1] *B.O.C. Handbook for Oxy-acetylene Welders.*

[2] M. Riddihough, "Hard Surfacing by Welding," *Transactions of the Institute of Welding,* May 1945.

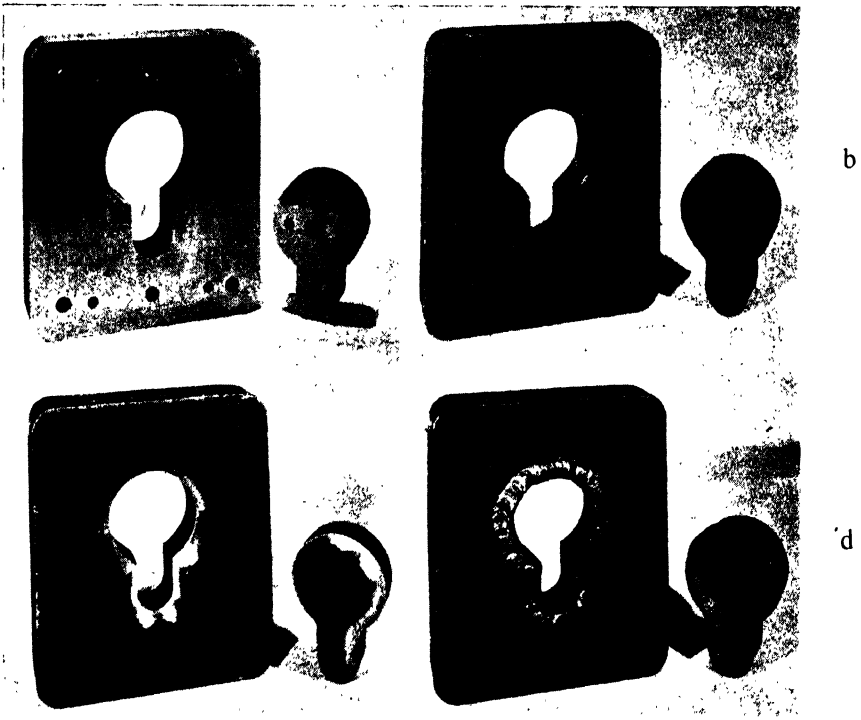


Fig. 5.6. Blanking Tool (*Metropolitan-Vickers*)

When depositing hard surfacing material by the metal-arc welding process, precautions similar to those already mentioned have to be taken, the preheating temperature being chosen according to the type of base metal to which the hard surfacing material is applied. For mild steel a preheating temperature of 150–250°C. is usually sufficient, whilst hard alloys, such as high speed tool steel, should be softened at 800°C. to prevent cracking. Cast iron should be preheated to about 400–600°C.

An interesting application of hard facing by the atomic hydrogen process is the repair of worn or the building up of new cutting edges in blanking tools by depositing a hardenable high carbon steel.

Considerable savings in material and labour have been made, for instance, in the manufacture of blanking tools (Fig. 5.6 a). The body is flame-cut out of mild steel plate. The cut-out internal piece is used as punch, the outer piece as die (Fig. 5.6 b). The edges of both, on which the hardenable material is to be applied, are chamfered (Fig. 5.6 c) and high carbon steel deposited (Fig. 5.6 d). The high temperature obtained with the atomic-hydrogen arc results in great welding speed and, therefore, little distortion, and the hydrogen shield prevents oxidization. Loss of carbon is counteracted by the use of filler rod material of extra high (0·10–1·25 per cent) carbon content, which results in a carbon content of about 0·75 per cent in the deposited metal.[1] After welding, the tool is rough-ground and afterwards hardened and tempered in the usual way.

[1] See also "Atomic Hydrogen Welding with Control of Carbon," *Welding*, October 1947.

CHAPTER VI

WELDING NON-FEROUS METALS

Copper and Copper Alloys.[1] The so-called "tough pitch copper" commonly used in general engineering contains oxygen, and copper oxides are found in the cast condition causing porosities and low ductility in the zones around the weld. Bronze welding, which does not melt the parent material, is advantageous in this case.

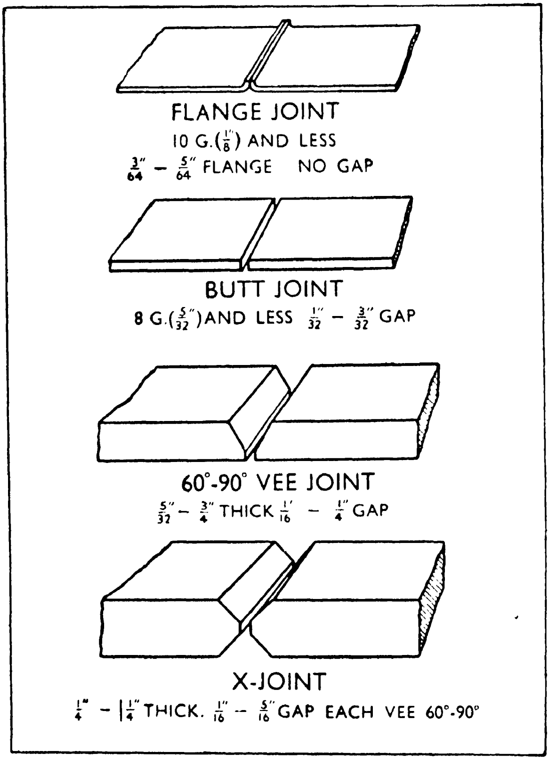

FLANGE JOINT
10 G.($\frac{1}{8}''$) AND LESS
$\frac{3}{64}''$ – $\frac{5}{64}''$ FLANGE NO GAP
BUTT JOINT
8 G.($\frac{5}{32}''$)AND LESS $\frac{1}{32}''$ – $\frac{3}{32}''$ GAP
60°-90° VEE JOINT
$\frac{5}{32}''$ – $\frac{3}{4}''$ THICK $\frac{1}{16}''$ – $\frac{1}{4}''$ GAP
X-JOINT
$\frac{1}{4}''$ – $1\frac{1}{4}''$ THICK. $\frac{1}{16}''$ – $\frac{5}{16}''$ GAP EACH VEE 60°-90°

Fig. 6.1. (*B.O.C.*)

For welding purposes de-oxidized copper is used and, when *oxy-acetylene welding* this material, the filler rod should be of similar composition, a de-oxidizing agent such as phosphorus being usually added. A neutral flame should be employed, and oxidization should be prevented by painting a suitable flux on the edges to be welded and on the filler rod. In the case of excess acetylene in the flame, the molten copper will dissolve the available excess hydrogen, which in turn will combine to water vapour with the atmospheric oxygen, forming steam bubbles in the molten metal and causing porous welds.

---

[1] E. Davies, "Brazing and Welding of Copper," *Welding,* June–July 1946, and "Jointing of Brass," *Welding,* May–June 1947.

The recommended technique of flame adjustment for copper welding consists of starting with a carburizing (excess acetylene) flame, and then gradually reducing the acetylene supply until a slight trace of acetylene surplus is left, thus avoiding the danger of an oxidizing flame, without having too much acetylene. Due to the high heat conductivity of copper the blowpipe nozzle size should be larger than that used for welding steel, and in order to reduce the heat loss through dissipation it is often advisable to precede the welding blowpipe by a second preheating blowpipe travelling just ahead of the former. After-treatment of copper welds is sometimes recommended in order to prevent excessive grain growth in the copper adjacent to the weld, and to improve the mechanical properties of the welded zone. Hammering in the hot or cold state and, sometimes, annealing by heat treatment at about 600°C. are after-treatments which are frequently used. Recommended edge preparations are shown in Fig. 6.1. The leftward welding technique should be used (Fig. 6.2).

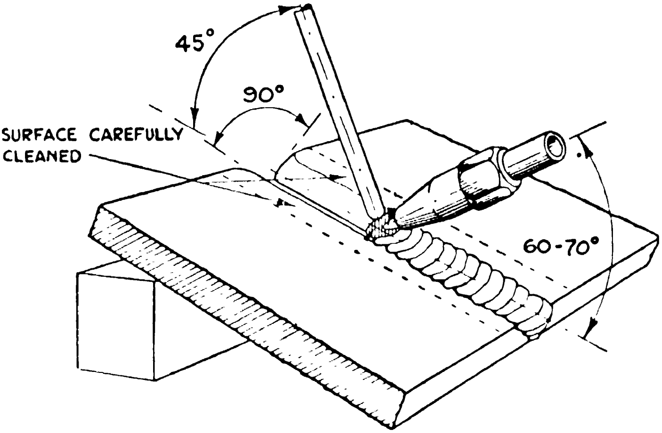


Fig. 6.2 (*B.O.C.*)

As the weld metal is more fluid than with steel it is often necessary to support the underside of an open joint, in order to prevent metal from running through.

Similar techniques are employed for welding copper alloys like brass, bronze, and monel metal, with the use of suitable fluxes and filler rod materials. The greatest problem in the welding of copper-zinc alloys is the avoidance of blow holes which may be caused through loss of zinc. The melting point of zinc (about 420°C.) is lower than that of the alloy, and the zinc vaporizes before the copper constituent begins to melt. Loss of zinc in this manner causes blow holes in the welds and reduces their strength.

An oxidizing flame will help in counteracting the above danger, as it causes the formation of a zinc oxide skin on the surface of the molten metal, thus preventing the escape of zinc vapours.

The required amount of surplus oxygen is best determined by welding a test piece, and reducing the acetylene supply until zinc fumes cease to appear out of the molten pool.

When welding tin bronzes a neutral flame has to be used, and in case of lead bronzes formation of lead oxides has to be prevented by using a suitable flux.

The *arc welding* process with its concentrated heat is highly suitable for the welding of copper and its alloys above a certain plate thickness. It should be carried out with D.C. and the electrode connected to the positive pole of the generator. Silicon bronze and tin bronze electrodes are employed. Heavily coated electrodes are often preferred in the metal-arc process as preheating is not so essential as with lightly coated ones. A flux should be used with the carbon arc process.

Most copper alloys can be welded by the *atomic hydrogen process*, a limitation being the zinc content of brass and bronze, which must be below 40 per cent.[1]

Resistance welding, although possible, is rather difficult due to the low resistance of copper. Very high currents and short welding times, and electronic control of the welding machines are essential. Brazing is often preferred for these materials, especially when small thicknesses have to be joined and when autogenity is not essential.

Aluminium and Aluminium Alloys. The melting points of these are very low (about 650–660°C. as compared with 1400–1500°C. for steel), their thermal and electrical conductivity are high, and they have an affinity for oxygen, particularly at welding heat. Although pure aluminium has good corrosion resistance, this is lowered by impurities, especially silicon and iron. The pure metal is, therefore, employed as parent material and for filler rods, if the components to be produced have to be highly corrosion-resistant. But for welding aluminium alloys, silicon aluminium filler rods are often used, because the danger of hot-shortness is reduced and the melting point is lower than that of pure aluminium, reducing the probability of residual stresses and cracks due to shrinkage of the filler metal. The coefficient of expansion of aluminium and its allows is high, and distortion has to be minimized by avoiding long welded seams in large flat areas of material.

---

[1] I. H. Hogg, "Atomic Hydrogen Welding," *Metropolitan-Vickers Gazette*, October, 1945.

Before welding these metals moistures, grease, and dirt must be removed from the surfaces by heating (200°C.) and scratch-brushing. In fusion welding, the oxide film which forms easily on the surface has to be eliminated, as it prevents proper metal-flow during welding. (Aluminium oxide has a higher melting point than aluminium.) For this purpose a deoxidizing flux is used, but must subsequently be removed as it may cause corrosion in time. It is generally recommended to wash the welded article in warm water, and to brush it with a wire brush. Dipping into a warm 5 per cent solution of nitric acid and afterwards rinsing in warm water is very effective, and in special cases a second washing operation a few days after the first one will remove the last trace of flux. Fusion welded joints, particularly fillet welds, which are likely to trap the flux have to be avoided. Butt joints which are easily accessible are recommended (Fig. 6.3).

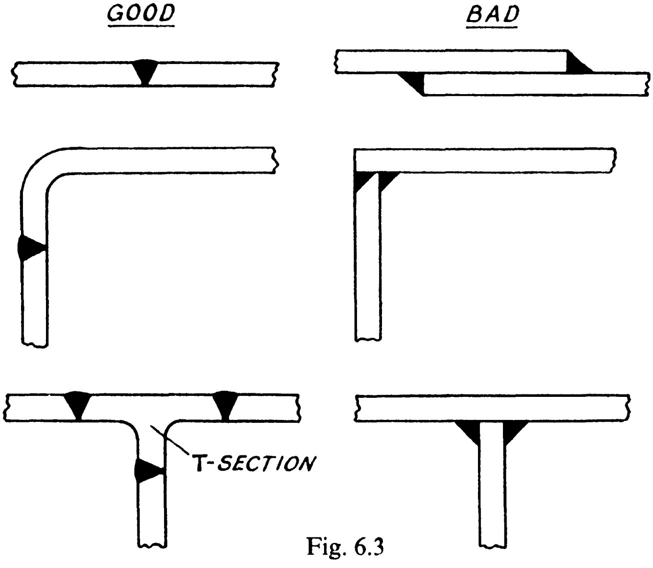


Fig. 6.3

A flux must even be applied in the case of *atomic-hydrogen welding* of aluminium alloys, as the reducing character of the atomic-hydrogen flame at 2080°C. does not come into effect at the low melting point of the material. Typical settings for atomic hydrogen welding are shown in Table 26.

TABLE 26

Atomic Hydrogen Welding of Aluminium Alloys[1]

Thickness (inches)	Tungsten electrode dia. (inches)	Current (amps.)	Hydrogen Consumption (cub. ft./min.)
0·039	$\frac{1}{16}$	15	0·39
0·079	$\frac{1}{16}$	20	0·44
0·16	$\frac{1}{16}$–$\frac{3}{32}$	29	0·44
0·24	$\frac{3}{32}$	37	0·54
0·39	$\frac{1}{8}$	48	0·54

For *oxy-acetylene welding*, a flame with slight acetylene surplus is recommended, in order to avoid oxidization, the blowpipe nozzle being one size smaller than for welding steel of equivalent thickness.[2] Flux should be applied to the edges to be welded and to the filler rod. It is recommended to mix a paste from the flux and alcohol, as water assists the formation of oxide. Cracking in long seams can be prevented by tacking the edges to be welded every 2–3 inches, and by leaving to the last the ends of the seam to be welded.

For welding aluminium alloy castings, filler rods of similar composition should be used, and preheating and slow cooling is often advisable.

Oxy-acetylene welding of duralumin or alclad is not recommended[2] due to the reduced tensile strength of the weld metal obtainable, and because of the danger of cracks near the weld.

Sheet material above $\frac{1}{16}$" thickness can be welded successfully by the *metal-arc* process. It is not recommended to attempt it for smaller thicknesses because of the concentrated heat, and because the heat distribution of the arc on the parent material cannot be as finely controlled, as in oxy-acetylene welding. For the same reason unequal thicknesses are difficult to weld, as the thinner material would melt away faster than the thicker. Tapering of the thicker section (Fig. 6.4) is, therefore, advisable.

---

[1] I. H. Hogg, "Atomic Hydrogen Welding", *Metropolitan-Vickers Gazette*, Oct. 1945.

[2] *B.O.C. Handbook for Oxy-acetylene Welders.*

As the molten metal is very fluid, downhand welding is generally necessary, and a grooved backing strip of steel, copper, or asbestos is used for stopping molten metal from running through. Preheating of castings can sometimes be avoided by using for first runs current values which are higher than normal; owing to the spatter caused they should be reduced to normal as soon as the flow of metal is satisfactory.

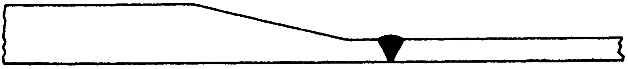


Fig. 6.4

D.C. is recommended and the electrode should be connected to the positive pole of the supply. Recommended welding conditions are shown in Table 27. The electrode coating provided serves for controlling the arc and removing surface oxidation. After welding, the slag should be carefully removed to prevent corrosion (see flux removal, page 121).

TABLE 27

Metal-Arc Welding of Aluminium Alloys[1]

Thickness of material (inches)	Gauge of electrode	Current range (amps.)	Plate gap recommended
$\frac{1}{16}$	12	40–45	Close butt
$\frac{3}{32}$	10	80–95	Close butt
$\frac{1}{8}$	8	95–105	Close butt
$\frac{3}{16}$	6	130–150	$\frac{1}{16}$ in.
$\frac{1}{4}$	4	190–210	$\frac{1}{8}$ in.
$\frac{3}{8}$	4	200–225	$\frac{3}{16}$ in. or bevelled 70° with $\frac{1}{16}$ in. step

[1] Murex Welding Processes Ltd.

The aluminium silicon electrodes generally used (except for welding pure aluminium) should be stored at not less than 60°C. since moisture in electrode or coating causes porosity. The water dissociates in the arc into oxygen and hydrogen, the hydrogen dissolving in the molten metal and being trapped when the latter solidifies. Slightly damp electrodes can often be recovered by drying at about 120°C. for an hour, and allowing to cool very slowly, but about 500°C. is required for safely preventing porosity.[1]

Due to the high conductivity of aluminium alloys, *resistance welding* currents have to be very high and welding times short (Table 28). To avoid heavy short time loads on one phase of the supply line, energy-storage welding equipment is often employed. This provides high current for a short time, at about 10 per cent of the power demand which would be necessary with normal equipment.

TABLE 28

Machine Settings for Spot Welding Aluminium Alloys[2]

Thickness of each plate		Electrode tip diameter (truncated cone, 160° included angle)*	Welding current	Electrode pressure	Welding time
S.W.G.	inches	inches	amps.	lb.	secs.
18	0·048	0·221	22000	500–700	0·16
16	0·064	0·253	24000	500–700	0·16
14	0·080	0·285	28000	600–800	0·20
12	0·104	0·330	32000	800–1000	0·20
10	0·128	0·375	35000	800–1200	0·25

* Dome-shaped electrodes, 1–2″ radius, also recommended.

Spot welding electrodes must be of hard material, having high electrical and heat conductivity, and able to carry the welding currents and to withstand the welding pressures. From time to time they should be cleaned of the aluminium alloy coating which forms over their faces, and which increases the resistance in the circuit and makes them stick to the components.

Sheet surfaces have to be cleaned from grease and dirt prior to spot welding, but the removal of the usual oxide coating found on some alloys, though desirable, is not essential. Cleaning may be done by chemical or mechanical means, but when using the latter on alclad care must be taken not to damage the protective coating.

[1] V. J. D. Hill and D. C. F. Lunn, "Porosity of Metallic Arc Welds Made with 5 per cent Silicon Aluminium Alloy Electrodes," *Welding*, February 1947.

[2] Converted from : *Resistance Welding Manual*, published by the Resistance Welder Manufacturers' Association, Philadelphia, Pa., U.S.A.

When *seam welding* aluminium alloys, the current must be supplied and cut off exactly in synchronism with the voltage supply. This can only be achieved by means of electronic controls described later. Weld spacings up to 2″ pitch can be arranged, overlapping spots being required for producing gas-tight welds (Table 29).

TABLE 29

Machine Settings for Producing Continuous (Gas Tight) Seam Welds in Aluminium Alloys[1]

Thickness of each plate		Spots per inch	Welding current	Wheel pressure	On + off time	On time
S.W.G.	inches		amps.	lb.	secs.	secs.
18	0·048	12	36000	860	0·16	0·03
16	0·064	10	38500	960	0·19	0·05
14	0·080	9	41000	1090	0·26	0·07
12	0·104	8	43000	1230	0·34	0·09
10	0·128	7	45000	1350	0·47	0·13

Projection welding and flash welding[2] of aluminium alloys can be carried out successfully, the current density required for flash butt welding aluminium being at least 100000 amps. per square inch of welded area. Machine settings for projection welding have to be established experimentally for each individual application, due to the great number of variables encountered.

Aluminium has also been successfully spot and seam welded to steel, by first silver-plating the steel surface to be welded.[3] Pressure forge welding of aluminium alloys has also been carried out by heating the parts concerned and forging them together under the hydraulic press.[4]

---

[1] Converted from: *Resistance Welding Manual*, published by the Resistance Welder Manufacturers' Association, Philadelphia, Pa., U.S.A.

[2] R. Della Vedowa and E. A. Reynolds, "Progress Report on the Flash Welding of High Strength Aluminium Alloys," Welding Research Supplement, *Welding Journal*, February 1947.

[3] W. F. Hess and E. F. Nippes, "A Method for Welding Sheet Aluminium to S.A.E. 4140 Steel," Welding Research Supplement, *Welding Journal*, March 1946.

[4] R. F. Tylecote, "Pressure Welding of Light Alloys Without Fusion," *Transactions of the Institute of Welding*, November 1945.

TABLE 30

Range of Currents and Gas Consumption for Argon-Arc Welding for Different Thicknesses of Magnesium Alloys[1]

S.W.G.	Filler rod dia. (inches)	Tungsten electrode Dia. (inches)	Torch head	Approximate welding current (amps.)	Argon consumption (litres/min.)	Edge preparation
20	$\frac{3}{32}$ to $\frac{1}{8}$	$\frac{3}{32}$ to $\frac{1}{8}$	Small	18–25	2 to 2·5	Close butt, square edge, or flanged edge.
16	$\frac{3}{32}$ to $\frac{1}{8}$	$\frac{1}{8}$ to $\frac{3}{16}$	Small	30–50	2 to 3	Close butt, square edge.
14	$\frac{3}{32}$ to $\frac{5}{32}$	$\frac{1}{8}$ to $\frac{3}{16}$	Small	50–70	3	Close butt, square edge.
10	$\frac{1}{8}$ to $\frac{5}{32}$	$\frac{3}{16}$	Small	60–90	3 to 3·5	Close butt, square edge or bevel, 90° inclusive.
3	$\frac{1}{8}$ to $\frac{5}{32}$	$\frac{3}{16}$ or $\frac{1}{4}$	Small or large	70–100	3·5	Double bevel, 90° inclusive.
Over 3	$\frac{5}{32}$ to $\frac{3}{16}$	$\frac{1}{4}$	Large	Up to 120	4	Double bevel, 90° inclusive

NOTE. These figures are for guidance only.

[1] British Oxygen Co., Ltd.

Magnesium Alloys consisting of up to 90 per cent magnesium and—according to requirements—some aluminium, cadmium, copper, manganese, nickel, silicon, and zinc, combine low weight (about 65 per cent of aluminium) with relatively high strength and corrosion resistance to acids. Magnesium has a high affinity to oxygen and easily ignites when overheated. For *oxy-acetylene welding,* a neutral or slightly reducing flame (excess acetylene) should be used with a blowpipe nozzle one size smaller than for welding aluminium.[1] The material must be thoroughly cleaned, and preheating is recommended for castings. A flux preventing ignition should be painted on top and bottom of the area to be welded, but subsequently be removed because of its corrosive action (see page 121). The need for flux is eliminated in the *argon-arc process,* which was originally developed for the particular purpose of welding light, especially magnesium, alloys. The argon shroud protects the weld metal during welding, and the heat in the arc penetrates and disperses the oxide film on the surface of the parent material. Removal of the protective coating given to all magnesium alloy sheets is necessary only on the top side of the sheet at the area to be welded. The coating on the bottom side should be left, as it assists in holding up the underbead of penetration. Apart from needing no flux, the argon-arc welding technique is similar to oxy-acetylene welding, typical weld settings being shown in Table 30. Preheating of castings, up to 350°C. is required, except with small components.

For spot welding magnesium alloy sheet, high welding currents, accurate control of time, current, and electrode pressure are essential Chemical cleaning of the surfaces considerably improves the life and efficiency of the electrode tips[2] which should be of the domed type. Typical machine settings are shown in Table 31.

---

[1] *B.O.C. Handbook for Oxy-acetylene Welders.*

[2] W. F. Hess, T. B. Cameron, and R. A. Wyant, *Observations of Electrode Tip Pickup and Tip Life in the Spot Welding of Magnesium Alloy Sheet,* Welding Research Supplement, *Welding Journal,* August 1947.

TABLE 31

Machine Settings for Spot Welding Chemically Cleaned Magnesium Alloy Sheet[1]

Thickness of each plate	Dome tip radius	Peak Welding current*	Electrode pressure	Time to peak current
inches	inches	amps.	lb.	secs.
0·040	3	28000–36000	900	0·011
0·064	6	46000–58000	2400	0·026
0·125	10	62000–65000	4000	0·030

* Condenser Discharge (Stored Energy) Welder

[1] From W. F. Hess, T. B. Cameron, D. J. Ashcraft, and F. J. Winsor, *Optimum Welding Conditions and General Characteristics of Spot Welds in Magnesium Alloy Sheet*, Welding Research Supplement, *Welding Journal*, May 1947.

CHAPTER VII

PLANT AND EQUIPMENT FOR OXY-ACETYLENE WELDING

The plant and equipment required for oxy-acetylene welding consists of (I) Gas-producing and storing plant, and (II) Auxiliary equipment.

I. GAS-PRODUCING AND STORING PLANT

Oxygen (O_2) is obtained by fractional distillation of liquid air. The oxygen thus obtained has a high degree of purity. The welding efficiency is not greatly affected if the impurities in the oxygen are kept below 2 per cent, but their influence on the efficiency of flame cutting (see page 186) make it desirable to limit the impurities in oxygen to a maximum of 0·5 per cent. It is also important to keep the oxygen as far as possible free from water, as the water content will reduce the temperature of the welding flame, apart from corroding the walls of storage cylinders.

Oxygen is generally supplied as a gas in compressed form in steel cylinders (see Fig. 2.1). It can also be obtained in the liquid state, which has proved advantageous in the case of large installations, as transport in large tank-trucks is possible instead of the more dangerous way of carrying a load of cylinders filled with high pressure oxygen gas. Before use in the welding shop, the liquid oxygen has to be transformed into the gaseous state by special gasifying apparatus.

Steel cylinders with compressed oxygen are, however, most frequently used in our welding shops. The cylinders are solid drawn, and are usually supplied in sizes containing 200 cubic feet showing a pressure, when fully charged, of 120 atmospheres at 15°C. The oxygen volume in a cylinder is directly proportional to its pressure, and the oxygen consumption for a welding job can, therefore, be found from the pressure drop during the welding operations (Fig. 7.1).

The cylinders should not be kept in too hot surroundings, as the corresponding expansion of the oxygen will result in increased pressure. A safety valve or safety plug is usually provided, to prevent accidents caused by too high temperatures.

If, on the other hand, too rapid a drop in pressure occurs, i.e. due to the rate of gas consumption being too great, the cylinder valve may freeze, and the water contained in the oxygen may also be frozen.

In order to prevent this, specifications often limit the permissible rate of withdrawal.

Oxygen cylinders have to be treated with care, in order to prevent accidents. Oil, grease, or dirt easily ignite and cause explosions when coming in contact with high pressure oxygen. They should, therefore, be kept away from valves or hose connections. It has been mentioned before that cylinders must not be exposed to heat. Frozen valves must not, therefore, be thawed by using blowpipes or other flames, but only by means of hot water. Cylinders should be protected from shocks, e.g. by dropping, falling, or by being thrown, particularly at low temperatures when the cylinder material becomes rather brittle.

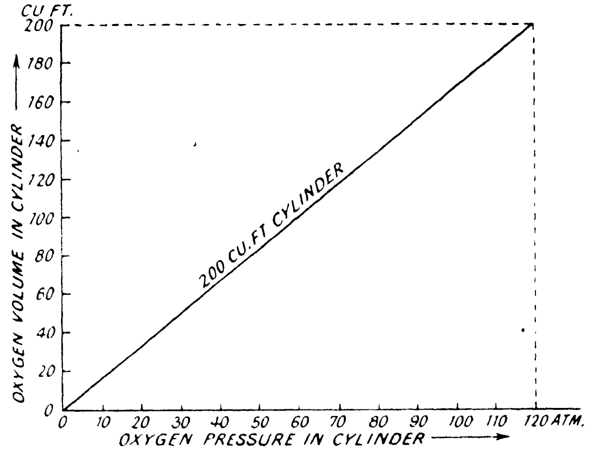


Fig. 7.1

Acetylene (C_2H_2) is either generated at the welding site or supplied in compressed form in steel cylinders. It is generated from calcium carbide (CaC_2) and water (H_2O). Calcium carbide is obtained by fusing together lime and coal. Pure calcium carbide contains 62·5 per cent Ca and 37·5 per cent C, but the calcium carbide as commercially available contains about 10 per cent impurities consisting of chemical combinations of sulphur, phosphorus, silicon, and nitrogen. Calcium carbide with water produces acetylene gas and calcium hydroxide:

$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2$$

Calcium carbide + water = Acetylene + Hydrated lime (sludge).

The impurities contained in the calcium carbide are partly left in combination with hydrogen in the acetylene, or they are found in the remaining calcium hydroxide.

In order to prevent generation of acetylene whilst the calcium carbide is supplied and stored, protection from dampness, even from humidity in the atmospheric air, is essential.

Pure acetylene has only a very faint smell, the stronger smell generally observed being caused by the impurities which are usually contained in the gas as obtained commercially. Acetylene is not dangerous under atmospheric pressure and if not in contact with air. A mixture of acetylene and air at a pressure above 1 atmosphere, and with an acetylene content between 2·8 and 73 per cent, is, however, highly explosive, especially at high temperatures. Drums containing calcium carbide should not, therefore, be opened by flame-cutting or by means of chiselling operations which might cause sparks.

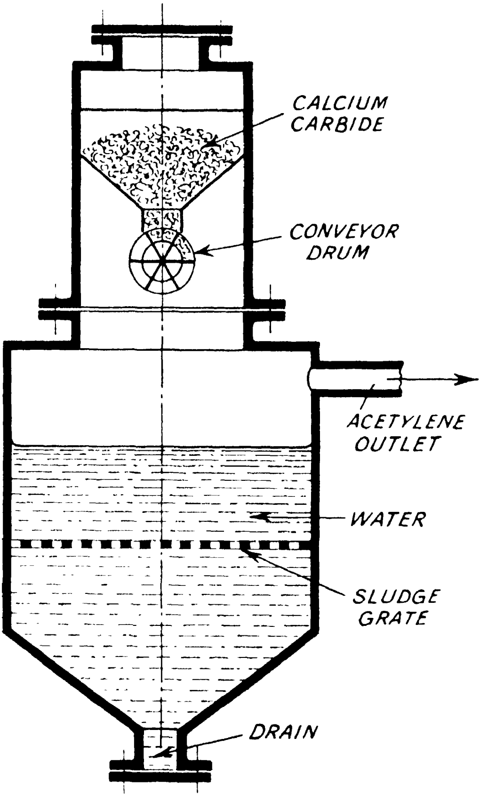


Fig. 7.2

Two basic principles of acetylene generations are used:

1. Calcium carbide is added to water (Fig. 7.2): The carbide falls

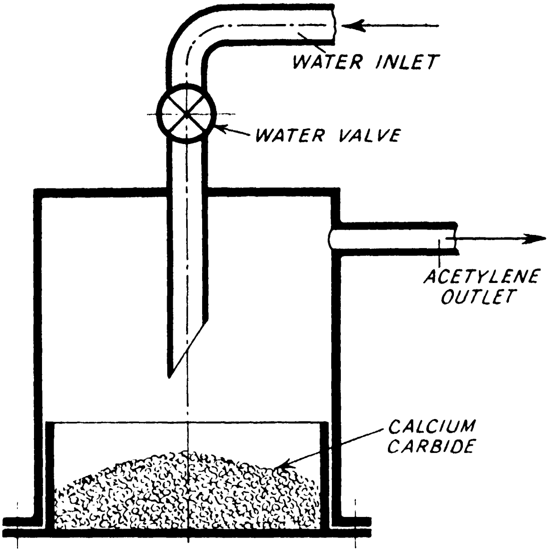


Fig. 7.3

into water from a container above the water tank, the exact quantities being controlled by means of a valve or other supply-device.

2. Water is added to calcium carbide (Fig. 7.3): Quantities of

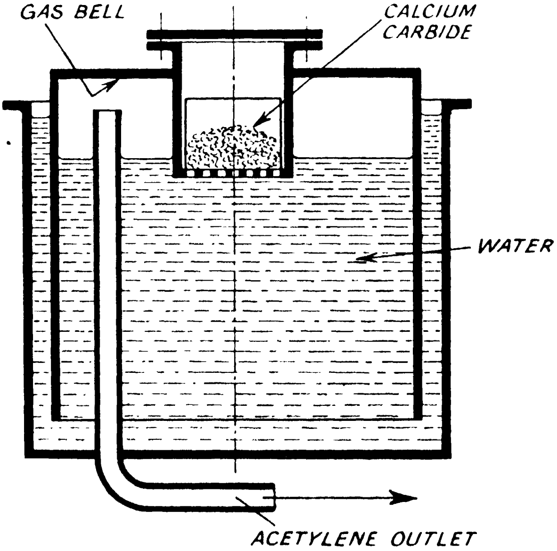


Fig. 7.4

water in accordance with the amount of acetylene required are dropped on calcium carbide.

Both principles can be put into practice in the so-called contact system in which the calcium carbide and the water are brought into contact and separated as required (Fig. 7.4). In the "immersion" contact method the water remains stationary and the carbide is moved towards it, and withdrawn by the generated acetylene itself, which raises the gas bell carrying the carbide container, or lets it sink into the water if the gas quantity gets below a certain value. This is, therefore, an application of system 1, whilst in the "displacement" method the water is moved towards the stationary carbide (system 2).

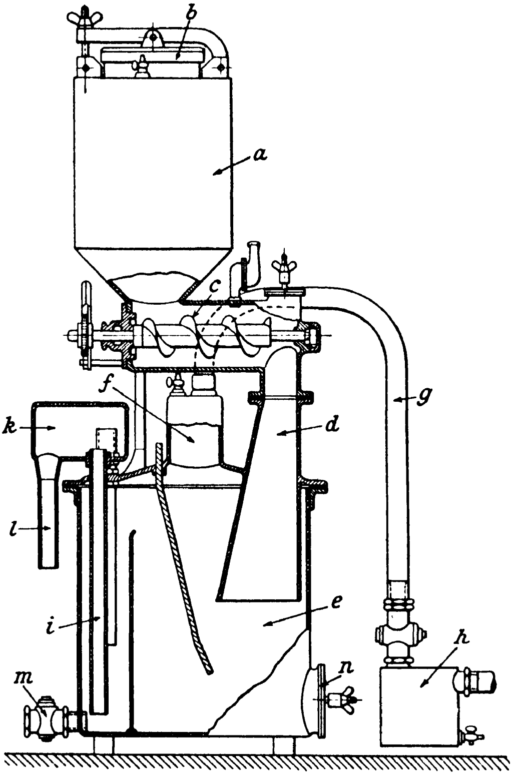


Fig. 7.5. Carbide-to-Water Generator (*B.O.C.*)

Fig. 7.5 shows a section through a typical carbide-to-water generator, as used in larger generating plants. The carbide is contained in the hopper *a* which must be kept closed (cover *b*) to exclude foreign matter. A conveyor *c* supplies the required quantity to the inlet pipe *d* through which it falls into the water tank *e*. The relatively large amount of water absorbs the heat of the reaction, and the acetylene gas rises in the form of bubbles through the water which at the same time cools and purifies it. The acetylene gas is collected in the gas chamber *f* above the water and conducted through the gas pipe *g* and condenser *h* to the gas holder on the welding site. Overflow pipe *i* conducts any overflow through overflow chamber *k* to drain pipe *l*. Sludge removal takes place through sludge cock *m* and hatch *n*.

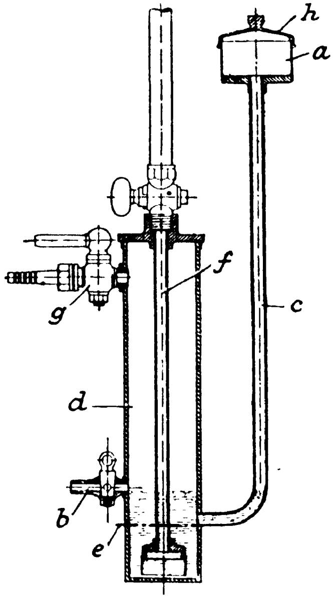


Fig. 7.6. Hydraulic back pressure valve (*B.O.C.*)

Full contact between the fresh carbide and the water is essential for efficient generation and the carbide must not become separated from the water by being embedded in the sludge (calcium hydroxide). In certain cases a grate at the bottom of the water container (see Fig. 7.2) holds the fresh carbide whilst the sludge falls through it and can be removed through a drain underneath.

In generators working on the carbide-to-water system, steps must be taken to prevent air from getting in contact with the acetylene, as a highly explosive mixture would result. This danger exists during the charging with new calcium carbide, during sludge removal, and by air being passed back from the blowpipe or the gas container. The first risk can be avoided through a primary charging hopper. This is filled and then closed airtight before opening the valve which allows the carbide to drop into the actual conveyor chamber. Air is often prevented from filling gas-free generator space by letting acetylene in instead, through valve arrangements which return acetylene from the gas holder to the generator as soon as the pressure in the generator drops below a minimum value, or as soon as the carbide door is opened.

To prevent ingress of oxygen or air from the blowpipe through the pipe connection, a hydraulic back pressure valve (Fig. 7.6) is usually provided. Through the cup *a* water is filled into the valve up to the level of test cock *b*. The maximum possible height of the water column is determined by the length of the filling pipe *c*, which creates a pressure greater than the highest permissible gas pressure. Furthermore, the internal dimensions of the valve body *d* are so arranged that, in case of the water being pressed right up the filling pipe *c*, the water level in the valve body itself does not fall below line *e*.

Acetylene enters through pipe *f* and rises in form of bubbles through the water in valve body *d*, leaving the same through cock *g* to the acetylene hose which is connected to the blowpipe. In case of excessive pressure building up through back-firing, through choking of the blowpipe nozzle, or through other reasons, the water is forced down in body *d* and up in pipe *c* until the inlet of the latter is uncovered, and the gas rises in bubbles through pipe *c*, and goes into the atmosphere by lifting lid *h*. Back pressure gas cannot enter pipe *f* as the water level in valve body *d* does not fall below line *e* and, therefore, remains always above the bottom of pipe *f*.

The danger of explosion which demands special precautions in generators of the carbide-to-water type is practically non-existent in those working on the water-to-carbide principle. On the other hand the advantage of having a surplus of water for gas-generating purposes and, therefore, complete gasification and washing and cooling of the generated gas, as obtained automatically by the former method, is lacking in the latter, unless specially designed for that purpose. It is also possible in the water-to-carbide type for too little water to come in contact with the carbide, causing decomposition of the latter, with dangerous heat development and deterioration of the quality of gas.

The water-to-carbide type generator (Fig. 7.7) working on the contact system (see page 133) avoids these difficulties.

The drawer type container *a* which contains carbide in several compartments is separated by its guiding tube *b* from the water in the generator body *c*. This water, however, completely surrounds tube *b* thus giving the necessary cooling effect to the carbide during the chemical reaction. Through a float-type water control valve *d* which is operated by the movement of cross bar *e* in gas bell *f* according to the amount of gas produced, the required quantities of water can be supplied to the carbide container through water pipe *g*.

The generator gas rises in gas collection pipe *h* into gas bell *f*. This is raised and lowered according to the quantities of gas withdrawn for welding purposes, thus closing or opening valve *d* and interrupting or restarting the generating process. As the gas has to pass through the water before reaching the top of the gas bell, it will be cooled and washed to the same extent as in the generator first illustrated.

The gas passes from the generator to the gas holder through a purifier, which removes chemical (hydrogen phosphide and hydrogen

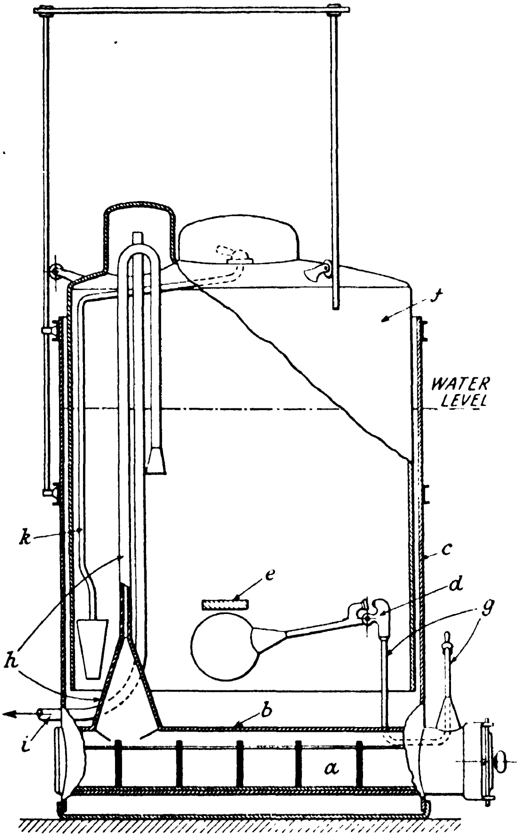


Fig. 7.7. Water-to-Carbide Generator (*B.O.C.*)

sulphide) and mechanical impurities and is frequently combined with a drier. Should the gas bell rise to its highest permissible position, excess gas escapes to atmosphere through pipe *k*. Hydraulic back pressure valves between gas holder and blowpipe are also used with such generators.

Acetylene cylinders. The solid drawn steel cylinders (Fig. 7.8) used in high pressure welding show a pressure, when fully charged, of 15 atmospheres (215 lb. per square inch). High pressure acetylene is not stable and for this reason the acetylene is dissolved in acetone which can absorb a large volume and relase it as the pressure falls. One volume of acetone at atmospheric pressure and at a temperature of 15°C. dissolves about 25 volumes of acetylene. The dissolving capacity grows in proportion to the pressure, so that, at the same temperature but at 15 atmospheres acetylene pressure, 1 volume of acetone absorbs about 25 × 15 = 375 volumes of acetylene.

To prevent explosions to which compressed acetylene is liable, the acetone in the steel cylinders is absorbed in a porous material which fills about 25 per cent of the steel cylinder volume, and divides the space into a large number of small compartments (the pores) and thus prevents a sudden reaction throughout the whole acetylene, should such a reaction be started by heating or other causes.

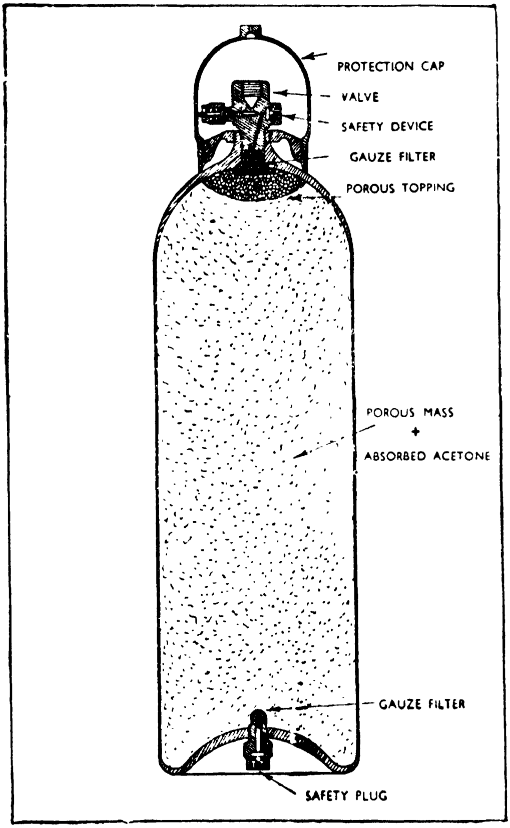


Fig. 7.8. Acetylene Cylinder (*B.O.C.*)

Although more expensive than low pressure gas generated by plants just described, high pressure acetylene in steel cylinders is very handy and efficient, being easily movable wherever required, particularly in places where only small quantities are used, and for repair work.

For use in the welding shop, the cylinders are fitted with pressure reduction valves (regulators) similar to those used for oxygen cylinders (see page 139). To prevent use of the wrong kinds of cylinders, acetylene cylinder outlet connections have left-hand threads, and oxygen connections right-hand threads.

Acetylene cylinders are usually supplied in sizes of a nominal acetylene content of 60 cubic feet, 100 cubic feet, or 200 cubic feet. Volume and pressure are not in linear proportion, and the gas consumption cannot, therefore, reliably be found from the loss in pressure in the cylinder. It is, therefore, recommended to determine the gas consumption by weighing the cylinder before and after use, considering that 1 cubic foot of acetylene weighs approximately 1·1 ounces (Fig. 7.9) within the range of temperatures and pressures involved. As with oxygen the rate of acetylene consumption has to be kept below a certain limit, viz. less than 20 per cent of the total cylinder content per hour. This is not because of freezing danger, as with oxygen, but because above that rate acetone may be drawn off. If work in the welding shop requires a higher rate of gas consump-

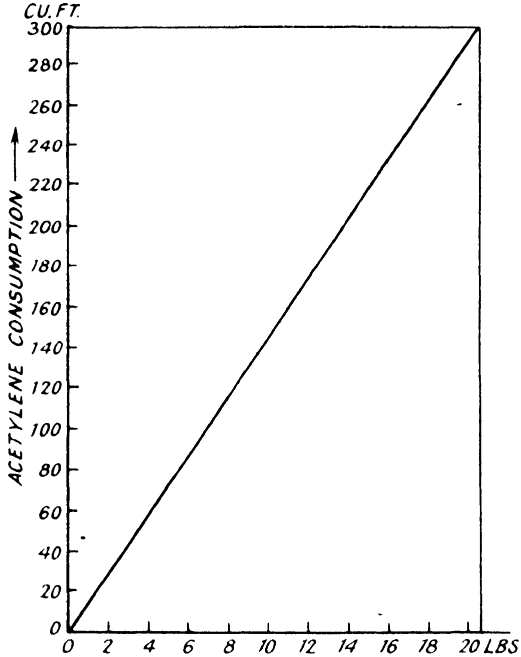


Fig. 7.9

tion, several cylinders have to be coupled in parallel. For very high gas consumption a manifold arrangement (Fig. 7.10) can be used.

Regarding exposure to heat, shock conditions, open flames, etc., acetylene cylinders have to be treated as carefully as oxygen cylinders They should not lie in a horizontal position when being used for welding, as acetone may run out.

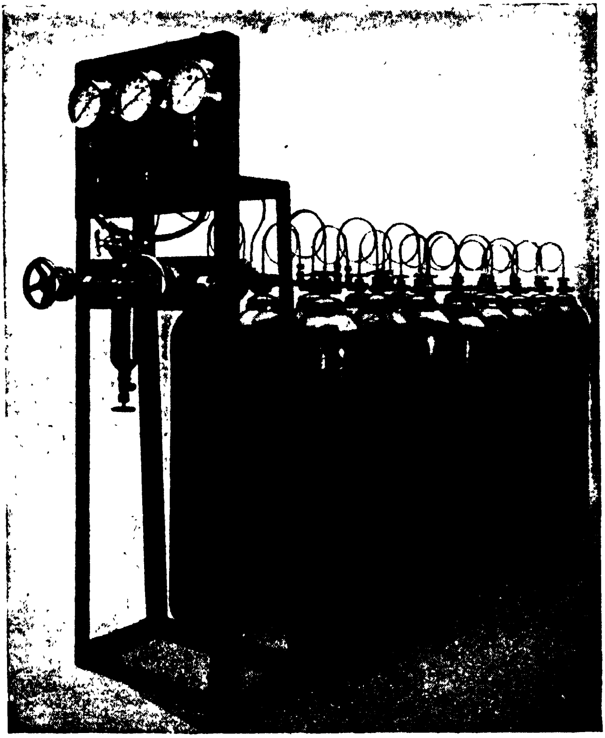


Fig. 7.10. Acetylene Cylinder Battery (*B.O.C.*)

To avoid confusion, *oxygen* cylinders are customarily painted *black*, and acetylene cylinders *maroon*.

II. AUXILIARY EQUIPMENT

Pressure Regulators. When the gases are stored in steel cylinders, a pressure reduction has to take place before they are passed to the blowpipes (see page 13). The single stage regulator (Fig. 7.11) is connected to the main cylinder valve at *a*, the pressure in the cylinder being read on pressure gauge *b*.

Hand-operated screw *c* serves to adjust the pressure exerted by spring *d* on diaphragm *e* which on the other hand is subjected to the pressure of the gas leaving the regulator through valve *f*.

If the pressure falls below the adjusted value, spring *d* pushes diaphragm *e* and valve disc support *g* to the left, thus opening valve *h* and letting more gas out. If the pressure is slightly above the adjusted value, diaphragm *e* is pressed to the right and valve *h* is closed by closing spring *i*. A safety valve *k* is also incorporated in this design.

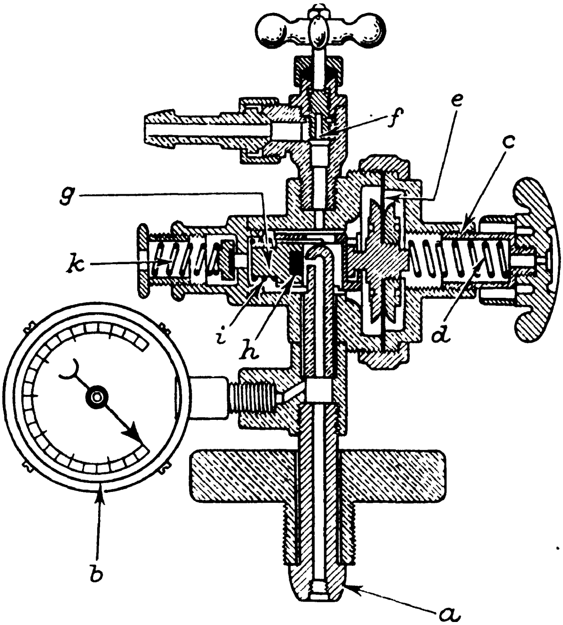


Fig. 7.11. Single Stage Pressure Regulator (*B.O.C.*)

With such a regulator, difficulties are experienced in case of long periods of welding, i.e. when the pressure drop in the cylinder becomes considerable. As the gas pressure in the cylinder acting on valve *h* (Fig. 7.11) is counteracted by spring *i*, the effect of the latter will increase with decreasing gas pressure. The lower the gas pressure in the cylinder, therefore, the greater will be the resulting pressure of spring *i* on valve disc support *g*, and the lower the pressure of the outgoing gas, which is helped by spring *i* in counteracting spring *d*.

To maintain the outgoing pressure constant during long welding operations the operator will have to make frequent adjustments in order to allow for the above-mentioned changing conditions.

The two-stage regulator (Fig. 7.12) overcomes this difficulty. The makers have proved that with this regulator the outlet gas pressure remains constant from the moment the full cylinder is first used, until through gas consumption the pressure in the cylinder has dropped to a value only slightly above that of the outlet pressure. The first stage valve *a* gives constant pressure reduction, the pressure in chamber *b* being controlled by the setting of spring *c*, which acts on diaphragm *d* and is not adjustable by the welder. The gas in chamber *b* travels through channel *e* to the second stage valve *f*.

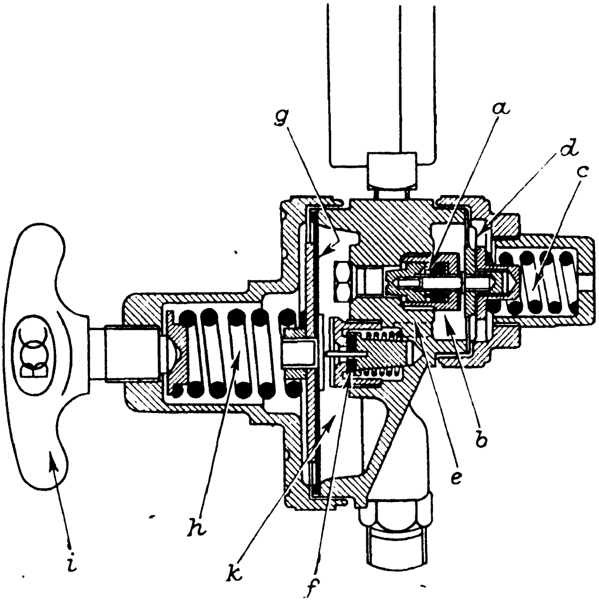


Fig. 7.12. Two Stage Pressure Regulator (*B.O.C.*)

Valve *f* is controlled by diaphragm *g* and by spring *h* which is adjustable by means of handle *i*, and thus determines the pressure in outlet chamber *k*. Since the first stage valve *a* is well-balanced, the pressure in chamber *b* can be kept accurately constant, and hence no variation in the reaction between the closing spring *h*, operating second stage valve *f*, and the gas pressure in chamber *b* will occur. Thus, the pressure in outlet chamber *k* will remain constant, whatever the pressure in the cylinder itself.

To prevent burning out of the hard rubber valve seatings, due to the rapid compression in the valve when the main cylinder valve is opened, fire-protecting sleeves are often fitted in the inlet tube, or turbulence of the gas is caused through the arrangement of the valve nozzle (see Fig. 7.11), in order to distribute the heat caused by the sudden compression at the reduction valve. Safety valves are usually incorporated in the high pressure side of the regulator, and safety cartridges prevent back-firing in case of explosions in the blowpipe connections.

Blowpipes. From the hydraulic back pressure valve which protects the low pressure acetylene gas holder, or from the reduction valves of the gas cylinders, rubber-canvas hose pipes carry the gases to the welding blowpipes which bring the required quantities of the two gases, oxygen and acetylene, together, and create the required exit speed (200–600 feet per second) of the mixture at the burner nozzle.

According to the acetylene plant with which they are used, we distinguish between low pressure and high pressure blowpipes. The former work on the injector principle, the acetylene being drawn into the mixing chamber by the oxygen. In the latter, both oxygen and acetylene are driven to the mixing chamber through their own pressures as adjusted by the regulators (see page 14).

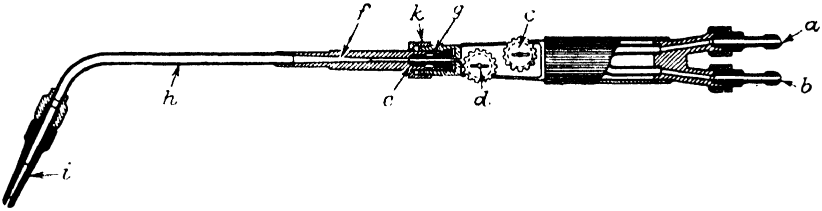


Fig. 7.13. Low Pressure Blowpipe (*B.O.C.*)

LOW PRESSURE BLOWPIPES. (Fig. 7.13). Oxygen enters through connection *a* and acetylene through connection *b*. The oxygen supply is controlled by hand-operated valve *c*, the acetylene supply by hand-operated valve *d*. From valve *c* the oxygen passes through the injector nozzle *e* into injector *f* where it creates a partial vacuum and thus draws the low pressure acetylene through channel *g* along the outside of *e* into the mixing chamber, and also provides a pressure of the gas mixture, which is high enough to enable the gas to travel at high speed through neck pipe *h* and burner nozzle *i*.

The quantity of gas passing through the burner nozzle does not only depend upon the nozzle size which is interchangeable (see page 13), but also upon the size of injector nozzle *e*, and this, too, is interchangeable according to the requirements of the welding job.

It will be noted that the mixing chamber *f*, neck pipe *h* and burner nozzle *i* (Fig. 7.13) are made in one piece which can be detached from the handle piece by unscrewing nut *k*. Injector nozzle *e* can be taken out easily and replaced by any size required. A tight fit of injector nozzle *e* on its seating in the handle piece is essential, as otherwise oxygen could mix with the acetylene prior to obtaining its high speed in the nozzle, and as the pressure in the acetylene supply line is very much lower than the oxygen pressure, back-firing of the explosive mixture could occur.

The precautions against back-firing in the blowpipe do not, of course, eliminate the need for the back pressure valve to protect the acetylene gas holder.

With increasing temperature the density of acetylene decreases at a higher rate than that of oxygen. If an injector blowpipe gets warm after prolonged use, a mixture containing excess oxygen and with it an oxidizing flame (see page 16) will result, and this has to be counteracted by suitable adjustments in the gas supply, which the welder has to carry out from time to time.

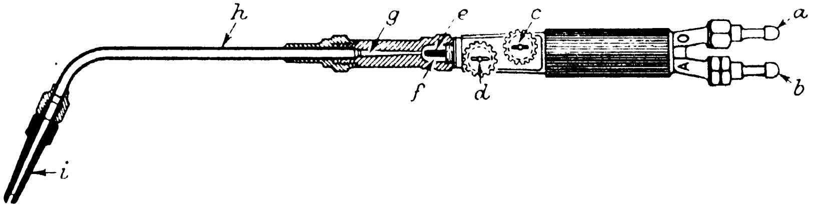


Fig. 7.14. High Pressure Blowpipe (*B.O.C.*)

HIGH PRESSURE BLOWPIPES. (Fig. 7.14). These do not need any injector nozzle arrangement, as both gases are supplied at equal pressure. The quantities of oxygen supplied at *a* and acetylene supplied at *b* are controlled by hand-operated valves *c* and *d* respectively. Oxygen is passing through bore *e*, acetylene through bore *f*, into the mixing chamber *g*, and the mixture passes through neck pipe *h* into the interchangeable burner nozzle *i*. As the heat radiation of the flame obtained with large burner nozzles is great, it is useful to have the blowpipe handle as far away from the flame as compatible with the requirements of easy blowpipe movement control. For this purpose neck pipe *h* is interchangeable, in order to enable the welder to use longer neck pipes when using the larger burner nozzles for the welding of thick plates. The recess which connects bores *e* and *f* with mixing chamber *g* is designed in such a way as to prevent back-firing. It is important to keep the orifice of the burner nozzles clean and undamaged, as a blocked orifice may cause back-firing and damage to the blowpipe. Soft copper wire is recommended for cleaning the orifice without damaging or enlarging it, and thus reducing its efficiency.

Under no circumstances should a non-injector type (high pressure) blowpipe be used connected to a low pressure gas supply system, as back-firing into the supply line may occur and serious explosions may be caused.

CHAPTER VIII

EQUIPMENT FOR ARC WELDING

THE main requirements of electric-arc welding plant have been set out before (see page 37). Various points require, however, detailed consideration.

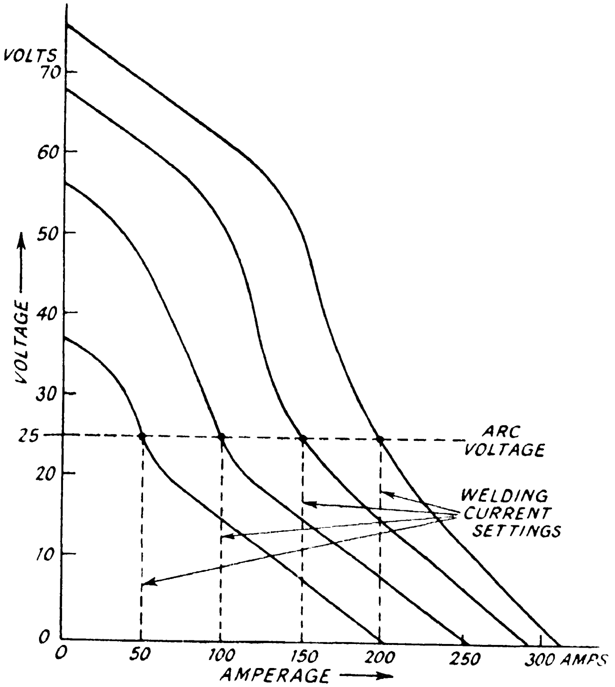


Fig. 8.1. Characteristic Curves of a D.C. Welding Generator (*Murex*)

D.C. Generators. The voltage drop in case of short circuit, the voltage recovery required for restriking the arc and again after the arc is struck, and the current rise above the set minimum value required for welding must, obviously, occur within the shortest possible time, and low electrical inertia of the welding plant is essential.

During the actual welding operations the theoretically most favourable conditions of the arc and its characteristics cannot always be maintained. The operator's hand will not always be so steady as to maintain absolutely constant arc length. It is desirable, however, that the resultant arc voltage variations do not cause the current value to vary considerably.

This can be achieved by the slope of the welding plant characteristic being as steep as possible around the values of the arc voltage corresponding to the minimum possible arc length (see Fig. 8.1).

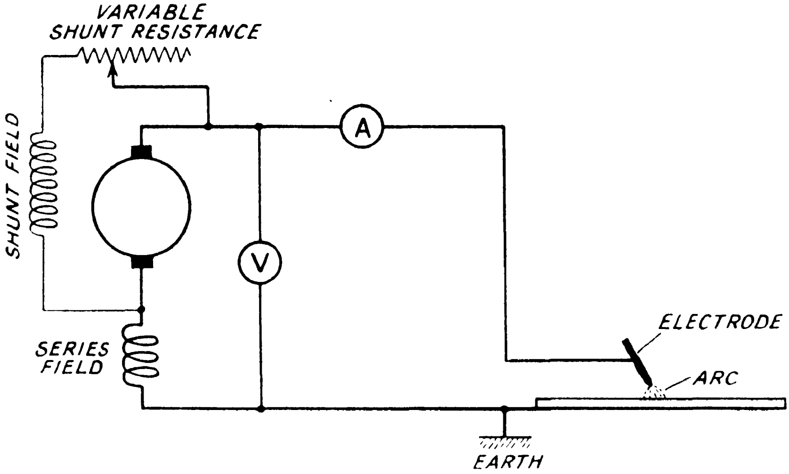


Fig. 8.2

It has been found, however, that in certain cases better penetration can be obtained with a flat characteristic of the welding plant, and a certain compromise has to be made, unless the plant is so designed as to make its characteristic variable (see Fig. 8.5).

The wiring diagram (Fig. 8.2) shows an arrangement in which the series winding is opposed to the self-excited shunt winding. Any increase of the main welding current which is carried by the series winding causes a decrease in the resultant magnetic flux and thus a decrease in the voltage. According to the required welding conditions, e.g. type and size of electrode, the welding current obtained at the arc voltage can be varied by altering the excitation of the machine by means of a variable shunt resistance. Fig. 8.1 shows the characteristics of the generator (Fig. 2.17) for the cases of the shunt resistance being set for 50, 100, 150 and 200 amps. welding current, at an arc voltage of 25 volts. It will be noted that the curves are fairly steep around the points of intersection with the horizontal arc voltage line of 25 volts, indicating that the current variations are only slight for voltage variations around the arc voltage.

The provision of shunt resistance control instead of series resistance control gives a higher electrical efficiency, as in the latter case part of the generated electric energy would be wasted in the resistance through being transformed into useless heat. Such an arrangement cannot, however, be avoided in the case of multi-operator welding equipment of the above type, which will be described later.

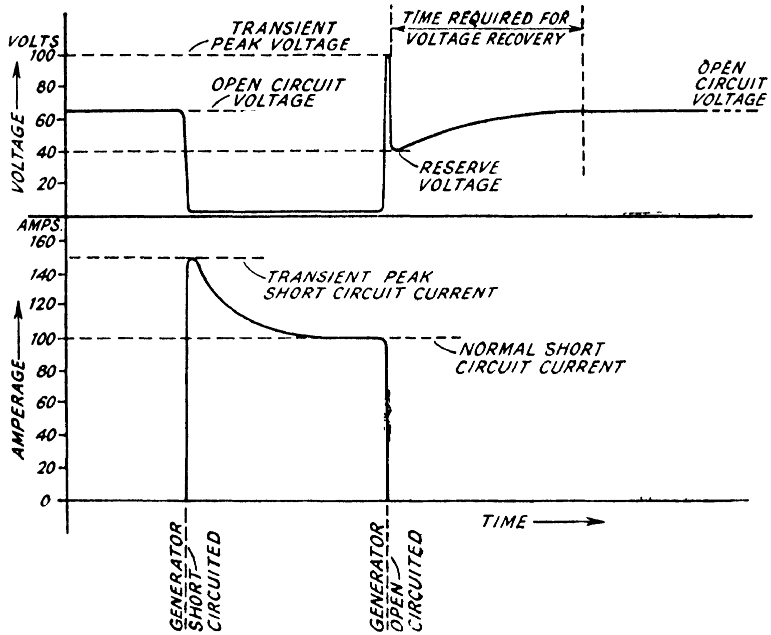


Fig. 8.3 (*Murex*)

It will be noted that with the arrangement (Fig. 8.1) different welding currents are obtained by altering the " position " of the characteristic curve, i.e. by changing the open circuit voltage through varying the shunt field (see Fig. 8.2). This results in different current values being obtained at the normal arc voltage.

The curves (Fig. 8.1) show the so-called static characteristic of the generator. Its dynamic characteristic, i.e. the reactions under actual welding conditions can be seen from an oscillogram taken during welding operations.

A typical oscillogram for a D.C. generator is shown in Fig. 8.3. As soon as the electrode touches the parent material, i.e. at short circuit conditions, the voltage drops rapidly from the value of the open circuit voltage to practically zero. The peak short circuit, about 50 per cent higher than normal, soon drops to the value of the latter.

The time required for the voltage recovery has to be as short as possible, and it is also important that the voltage does not drop below a certain value, here called the reserve voltage, which is required to maintain the arc.

It has been found that in the ordinary compound wound machine the required rate of voltage recovery is best obtained by using a separate exciter, because with this arrangement the field winding does not lose its magnetism during a short circuit.

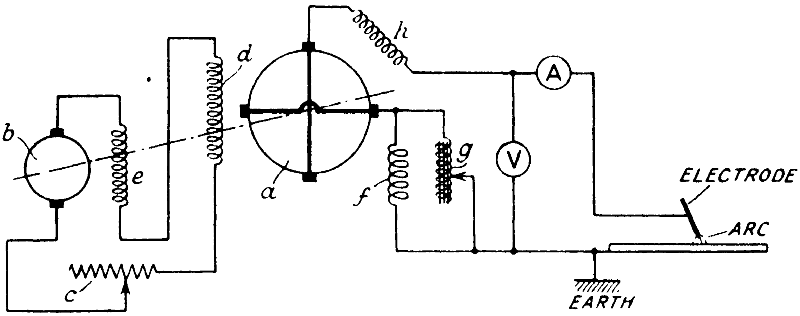


Fig. 8.4

Fig. 8.4 shows the wiring diagram of the machine shown in Fig. 2.16. The armature of the main generator is called *a*, that of the exciter *b*. A variable resistance *c* and the shunt field *d* for the main generator are in series with the exciter field *e*. By varying resistance *c* the current in field *d* can be controlled and with it the open circuit voltage of the main generator *a*. The current flowing in the series field *f* of the main generator can be varied by the resistance *g* connected in parallel with *f*. Interpole field *h* serves in the usual way for reducing sparking at the commutator brushes. Through varying resistance *g* alone, the welding current can be changed at fairly constant open circuit voltage (Fig. 8.5 A). Through varying resistance *c* alone, a range of characteristic curves with varying open circuit voltages can be obtained (Fig. 8.5 B).

Thus, a wide range of characteristics between curves (1) and (2) (Fig. 8.6) is covered by this machine, and by suitably combining the settings of resistance *c* and *g* (Fig. 8.4) different machine characteristics can be obtained for the same nominal arc voltage and amperage. For example, an arc voltage and amperage as indicated by point (3) (Fig. 8.6) can be obtained by a flat characteristic (curve 4), or a steep

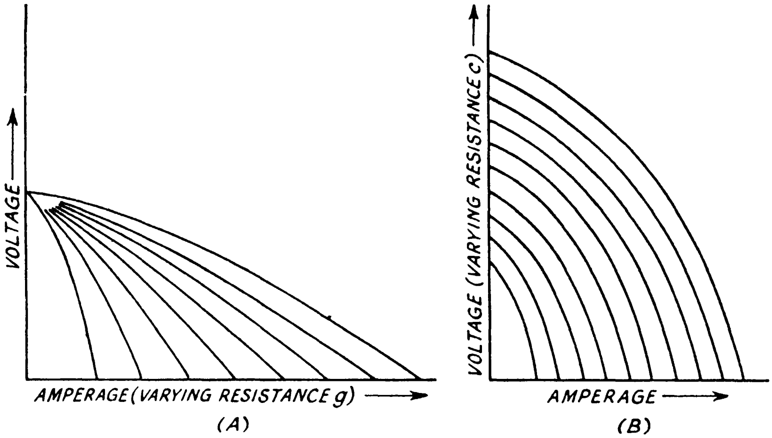


Fig. 8.5

one (curve 5). A flat characteristic (curve 4), in which the current increases considerably with falling arc voltage, e.g. shortened arc gap, gives a " digging " arc, i.e. an arc which is more suitable for overhead

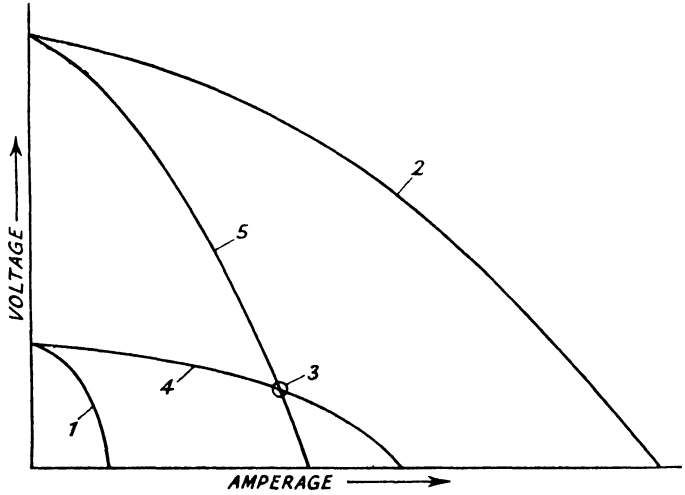


Fig. 8.6

welding, whilst ordinary downhand welding conditions would be covered by characteristic curve (5), where slight changes in arc length, and with it arc voltage, would only cause slight variations in the arc current.

Fig. 8.7 shows a typical section through the generator (Fig. 2.16) with A.C. motor drive.

In order to obtain high speed voltage recovery without using a separate exciter, the patented generator (see Fig. 2.17) has been developed. In this design the shunt and series windings are not opposed. The drooping characteristic is obtained by each pole piece being divided into two unequal parts A and B (Fig. 8.8). The effect of this arrangement can be explained by studying the phenomena occuring in one pole.[1] If the pole shown in Fig. 8.8 *a* is a north pole (indicated by N) the magnetic flux would (as shown by the arrows) enter at P and leave through the air gaps under A and B. Assuming that a current flows through the armature in the same direction as the normal short circuit current, the series and shunt windings, however, being disconnected, a cross field will be created by the armature reaction, and a magnetic flux circulating in the pole piece will result, entering it at the air gap under A and leaving it at the air gap under B. A will, therefore, become of south polarity (S) whilst B remains of north polarity (N). (Fig. 8.8 *b*). In view of the cross section of B being much smaller than the cross section of A, the former will be saturated without allowing all the flux entering at A to pass through B. Some of the lines of force entering at A due to the cross-magnetizing effect of the current in the armature will leave the pole piece on the top, and from there travel through the whole magnetic circuit of the machine, i.e. through the yoke, the other pole pieces, and the armature, generating a voltage opposite to the normal voltage of the generator, and thus acting in the

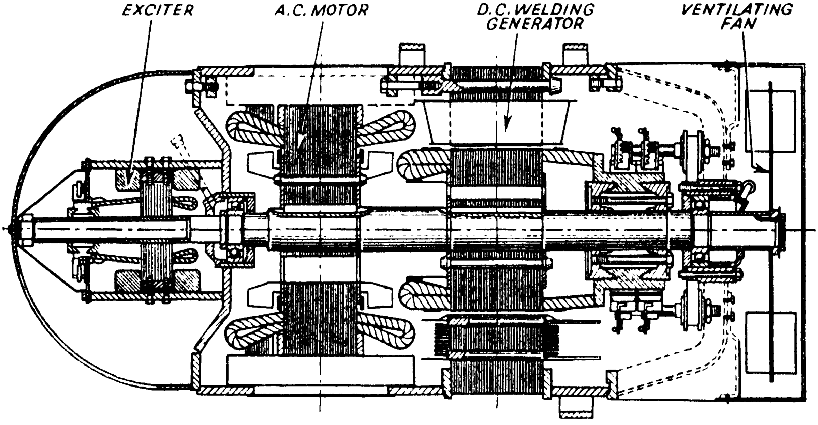


Fig. 8.7. Section through D.C. Welding Generator (*Lincoln*)

same way as an opposed winding. If the series winding is now connected to the armature, it will tend to cancel out the reverse magnetic flux shown in Fig. 8.8 *b*, and will create conditions as shown in Fig. 8.8*c*, i.e. no effective flux will go through the armature, and no voltage will be generated. The voltage drop will, therefore, be steep at high currents. The arrangement is, however, so designed as to give magnetic flux as shown in Fig. 8.8*d* under full short circuit conditions, in order to generate the voltage which is necessary to drive the current against the resistance in the armature.

---

[1] From Murex *Electric Arc Welding Manual*

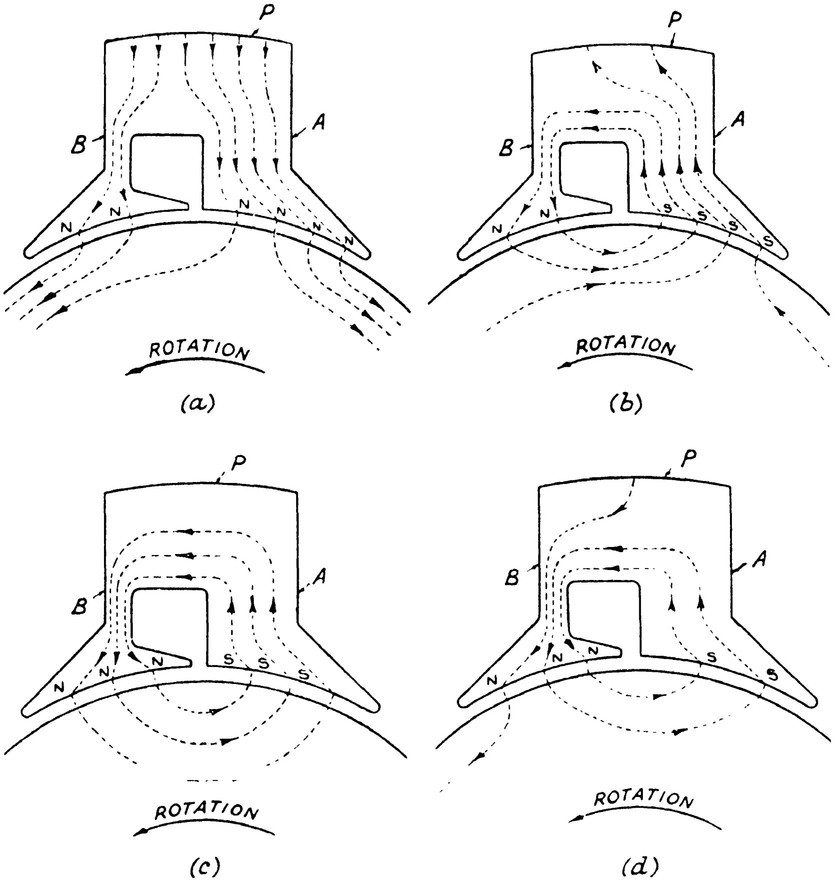


FIG. 8.8

Very low electrical inertia is obtained with the above design, and it is claimed that the speed of voltage recovery is not below that of machines with separate exciter.

The wiring diagram (Fig. 8.9) shows how a variable resistance *a* controls shunt field *b* and with it the open circuit voltage which can be varied between 72 volts and 40 volts, thus moving the "position" of the characteristic curves (see Fig. 8.10), whilst three different current ranges can be selected by tapping resistance *c*. The resistance is in series with series field *d* and interpole field *e*.

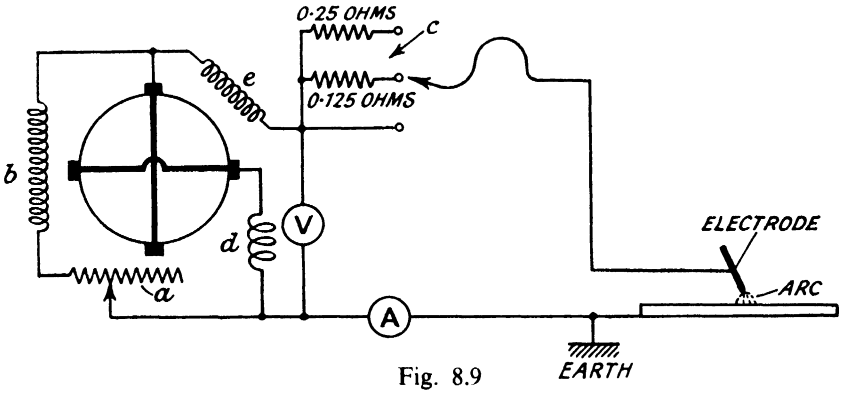


Fig. 8.9

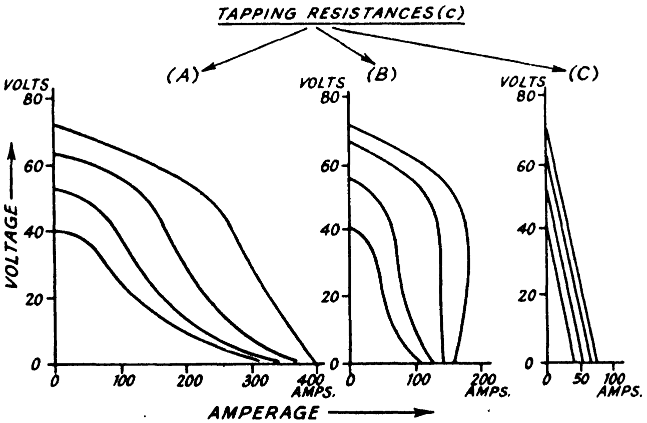


Fig. 8.10

The three sets of characteristic curves (Fig. 8.10) obtained with the above arrangement (Fig. 8.9), show the range covered by the setting with no series resistance inserted (Fig. 8.10 A), that with 0·125 ohms inserted (Fig. 8.10 B) and that with 0·25 ohms inserted (Fig. 8.10 C). It will be noted that an effect similar to that achieved with the dual control (Fig. 8.5) is obtained, although the range covered is not infinitely variable, but shows steps which are given by the ratio of the series resistances *c*.

Fig. 8.11 shows typical sections through the Murex generator. It will be noted that for reasons of mechanical strength the poles *a* are not completely split as indicated in Fig. 8.8, but that a small bridge-piece *b* is left, which does not, however, influence the effect as described before. A ventilating fan *c* is provided. The triangular shaft *d* for carrying the rotor armature is an interesting detail of the mechanical design of the generator.

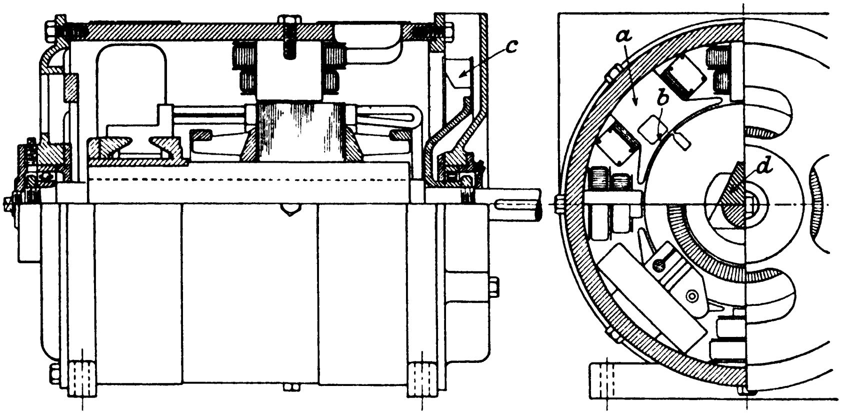


Fig. 8.11. Typical Sections through D.C. Welding Generator (*Murex*)

Cross field generators (Fig. 8.12[1]) utilize the cross field in the armature for generating the working current in brushes *a* which are at right angles to the cross field, i.e. in direction of the main field. The main series field (poles *b*) generates a voltage between brushes *c*. These are short-circuited, and the resulting high current generates a strong cross field in the direction *c*-*c*, even if the main field is only small. This cross field generates the main current which passes through the armature and thus creates a third field opposite to the main field. The effective cross field is, therefore, controlled by the difference between the original main field and the third field. An increase in the working current will result in an increase in the third field, thus reducing the difference between main field and third field, and automatically reducing the amperage of the working current. This means that in effect the current will remain fairly constant, and even under short circuit conditions high current peaks are avoided. With the excitation of the main field set for a certain working current (resistance *d*), only small variations of the latter will occur, i.e. the characteristic of the machine is very steep, and variations in arc length do not affect the current setting to any considerable degree.

---

[1] Patented by Rosenberg, see *ETZ* 1905, 1906, 1907.

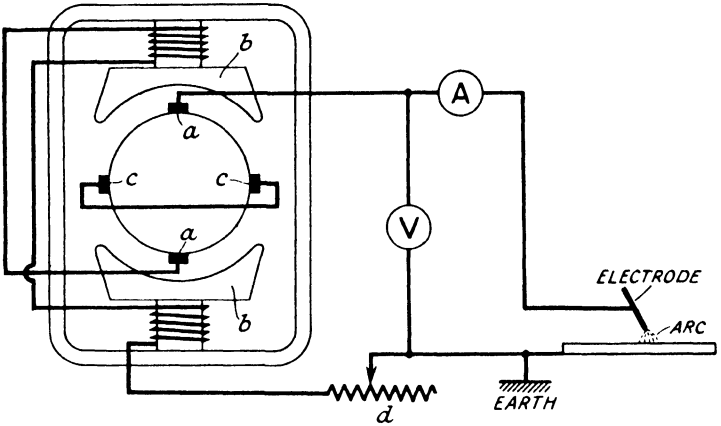


Fig. 8.12

The open circuit voltage of such machines depends entirely on the remaining magnetism in the main poles, and it is much lower than the arc-striking voltage created at the instant when a current begins to flow at all, i.e. when the electrode touches the parent metal. Cross field generators have a static characteristic as shown in Fig. 8.13, and open circuit voltages of about 30 volts have been obtained, although the arc-striking voltages have been considerably higher. It is, however, worth noting that the welder may loose the " feeling " of the correct arc length, as considerable variations in arc length, and with it arc voltage, do not affect the current in the same degree as is the case with other welding generators.

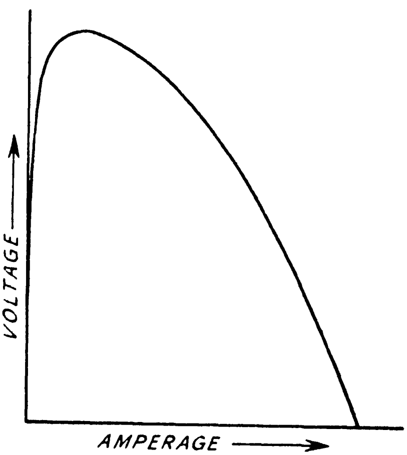


Fig. 8.13

A.C. Transformers. The portable single phase one-operator transformer (see Fig. 2.18) is arranged (Fig. 8.14) for different supply voltages (connections *a*, *b*).

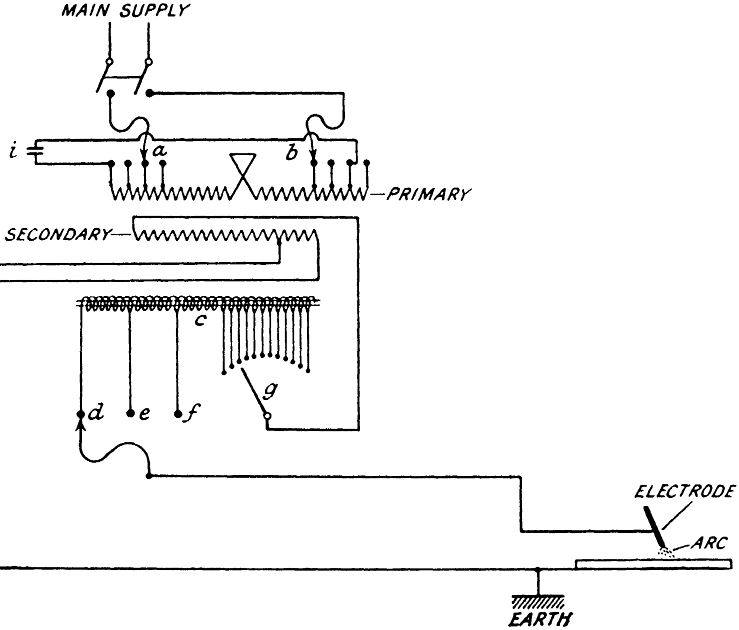


Fig. 8.14. Wiring Diagram for Welding Transformer (*Murex*)

The power factor is kept low, in order to obtain the phase angle between voltage and amperage waves, which is necessary to maintain the arc (see page 29). This phase shift is produced by the inductive reactance (*c*, Fig. 8.14) which also absorbs the difference between arc-striking and arc-maintaining voltage, thus giving the transformer a drooping characteristic (Fig. 8.15) similar to that of a D.C. generator.

By varying the reactance *c*, three ranges of secondary currents (tapping *d*, *e*, *f*) can be obtained, each range consisting of twelve current values (rotary selector switch *g*).

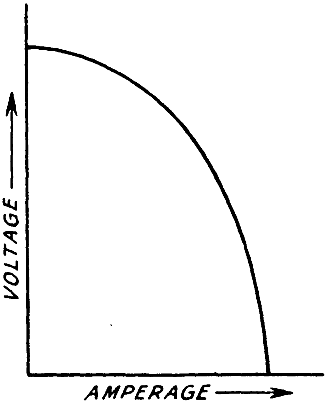


Fig. 8.15

Instead of the rotary switch *g* which taps different turns of the reactance coil, the current can also be varied by sliding the iron core in or out of the reactance *c*, thus altering the effective amount of iron remaining in the coil (see Fig. 2.19).

Two open circuit voltages, 80 volts for normal operations and 100 volts for special cases, can be obtained by means of rotary selector switch (*h*, Fig. 8.14). A condenser *i* can be provided for power factor (cos φ) correction, if required by the supply company.

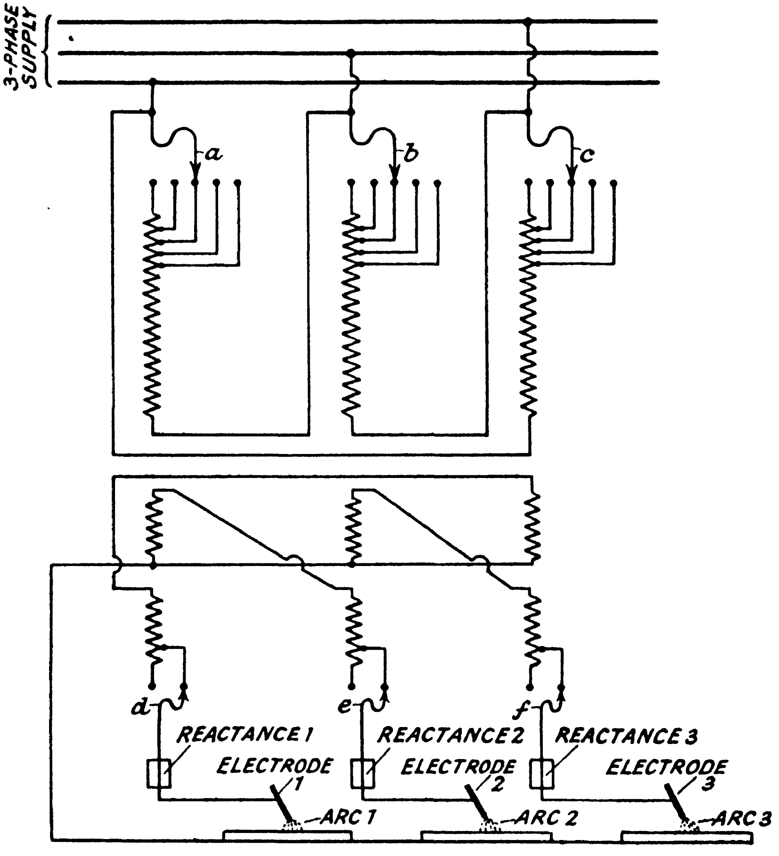


Fig. 8.16. Wiring Diagram for Three-operator Welding Transformer (see Fig. 2.20). (*Murex*)

It is of interest to note that the temperature rise in transformers allowed by B.S.S. 638 is lower for oil-immersed transformers than it is for air-cooled ones, the permissible continuous load current for the former being 60 per cent of the maximum continuous hand-welding current in case of non-automatic use, and 85 per cent in case of automatic use, whilst the permissible continuous load current for the latter is 70 per cent for non-automatic use and 100 per cent for automatic use. B.S.S. 638 also specifies that transformers must be double wound, thus keeping the supply circuit and the welding circuit electrically separated.

The three-operator welding transformer arrangement (Fig. 8.16) provides variable connections, *a, b, c,* for different supply voltages and tappings, *d, e, f,* for 80 and 100 volts open circuit voltages, as required. It does not throw the load out of balance, even if only one welder is working at a time.

Arc Stud Welding Equipment. The Cyc-Arc welding equipment consists of a standard D.C. welding generator, a controller unit and a hand tool holding the stud (Fig. 8.17).

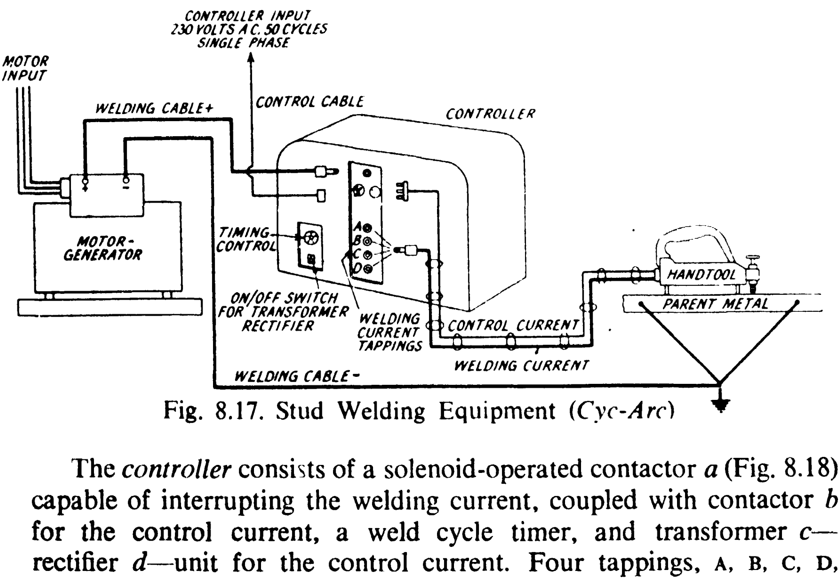


Fig. 8.17. Stud Welding Equipment (*Cyc-Arc*)

The *controller* consists of a solenoid-operated contactor *a* (Fig. 8.18) capable of interrupting the welding current, coupled with contactor *b* for the control current, a weld cycle timer, and transformer *c*—rectifier *d*—unit for the control current. Four tappings, A, B, C, D, from a series resistance give four settings of the welding current, apart from the current adjustment at the generator. The transformer-unit affords a reasonably constant voltage supply for the timer, and renders the operation of the equipment independent of variations in generator voltage due to the welding load. This ensures accurate control and repetition of the welding time cycle.

When push button *e* in the *hand tool* is pressed down, solenoid s_1 operating contactors *a* and *b*, is energized thus closing welding circuit (contactor *a*) and timing control circuit (contactor *b*). Through the timing control circuit (condenser charge timer *f*) solenoid s_2 is energized and lifts chuck *g* with the stud for a previously adjusted time, after which spring *h* presses the stud into the molten pool.

As the ironclad solenoid s_2, which lifts the stud and thus draws the arc, is shunt wound and energized from the transformer-rectifier unit, it is possible to operate the hand tool independently of the opening of the welding circuit, and so to obtain a fine control of the welding process. This in turn obviates the necessity of returning the stud to the parent metal at high speed to prevent freezing of the weld before the weld is consolidated, as the arc is maintained up to the instant of contact, and positive control of the arc length is possible.

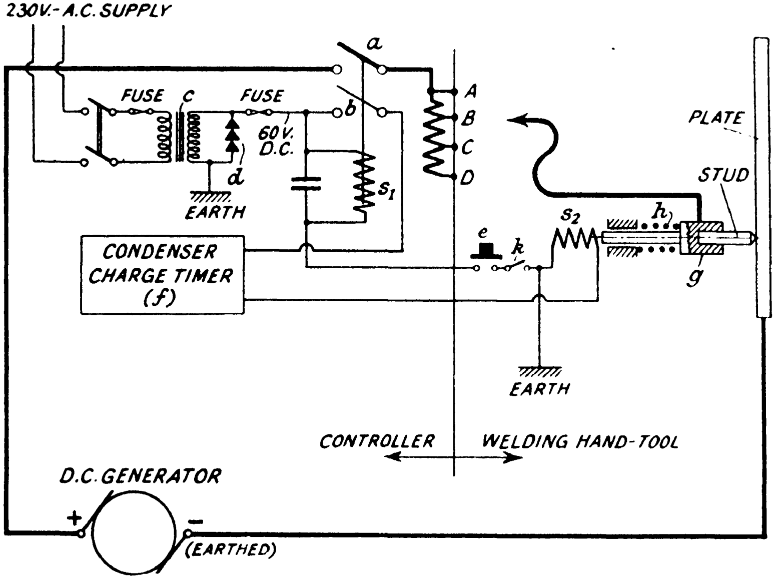


Fig. 8.18. Wiring Diagram of Stud Welder (Fig. 8.17)

A safety switch *k* in the contactor-solenoid (s_1) circuit is situated in the hand tool and mechanically operated by chuck *g*. This prevents repetition of the welding cycle unless a new stud is inserted in the chuck.

The schematic wiring diagram[1] of the *Nelson Stud Welder* (page 65) is shown in Fig. 8.19. Current is supplied by a standard D.C. welding generator. Immediately the stud *d* touches the plate (see also Fig. 2.36), a small current by-passes main welding current contactor *f*, through resistance *g* and relay solenoid *h* which are in parallel. The latter closes contactor *i*, thus lighting indication light *k* in the gun handle.

---

[1] The material used for showing the principles of the Nelson Stud Welder has been kindly provided by Cooke and Ferguson Ltd., Manchester.

This by-pass current arrangement which is a typical feature of the Nelson method, shows the operator by means of the indication light that good contact is made between stud and plate. The by-pass current is also capable of burning through small layers of paint and rust on the plate, thus establishing the conditions for successful welding. When closing trigger contact *a*, solenoid *l* is energized, which closes contacts *m*, *n*, and *o*. Contact *m* closes the circuit which energizes solenoid *p*. This closes contact *f* and with it the main welding circuit (indicated in thick lines). Contact *n* is in parallel with *a* and acts as retaining contact after *a* is released. Contact *o* closes the circuit for energizing solenoid *q*. This serves for opening contact *r* which is normally closed. The speed of the opening action of contactor *q*, *r* is controlled by an adjustable time delay air dash pot, and the time taken between closing contact *p* and opening contact *r* is the actual welding time, as the whole circuit is

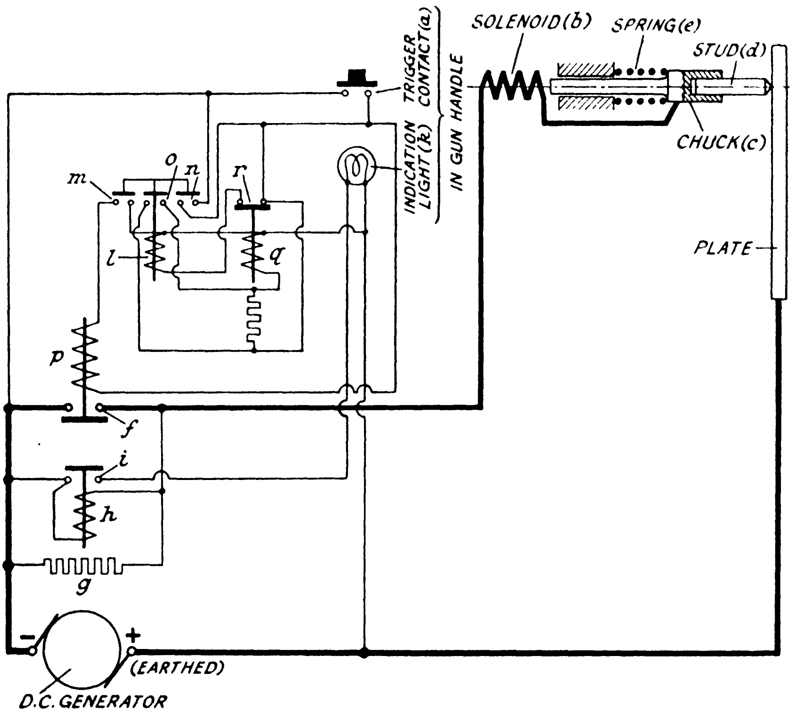


Fig. 8.19. Wiring Diagram of Stud Welder (Fig. 2.36)

interrupted immediately contact *r* opens. It will be noted that no separate supply is required to operate the control gear, the welding generator supplying both the main welding current and the auxiliary operating current. The time-setting of the air dash pot of opening contactor *q*, *r* has to be adjusted according to type and size of the studs to be welded.

Atomic Hydrogen Welding Equipment.

Transformer (Fig. 8.20).[1] The transformer primary *a* is arranged to allow for various supply voltages by means of a number of tappings b_1–b_{14} which have to be connected according to the available power supply. The welding current can be adjusted by means of tappings c_1–c_{10} of the reactor *d*. These tappings are selected by means of rotary tapping switch *e* (see also Fig. 3.1).

Push button *f*, in the auxiliary 110-volt circuit serves for closing contactors *g*, *h* in the main circuit by means of relay *i* in the auxiliary circuit.

Once the arc is struck between the electrodes and a current flowing in the main circuit, contactors *g*, *h* are held in the closed position by relay *i*, as relay *k* holds contactor *l* which is in parallel with *f*. The auxiliary circuit can be opened by pressing push button *m*, or by extinguishing the arc through increasing the gap between the electrodes and interrupting the main circuit and the current flowing through *k*, thus opening contactor *l*. In both cases relay *i* is de-energized and main contactors *g*, *h* are opened, thus cutting off the power supply.

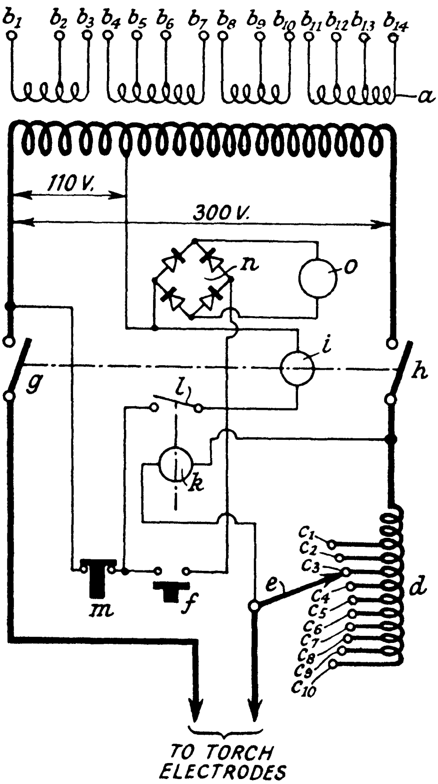


Fig. 8.20

Rectifier *n* controls solenoid-operated hydrogen gas valve *o* by opening it automatically in case of the current supply being "on",

---

[1] Metropolitan-Vickers.

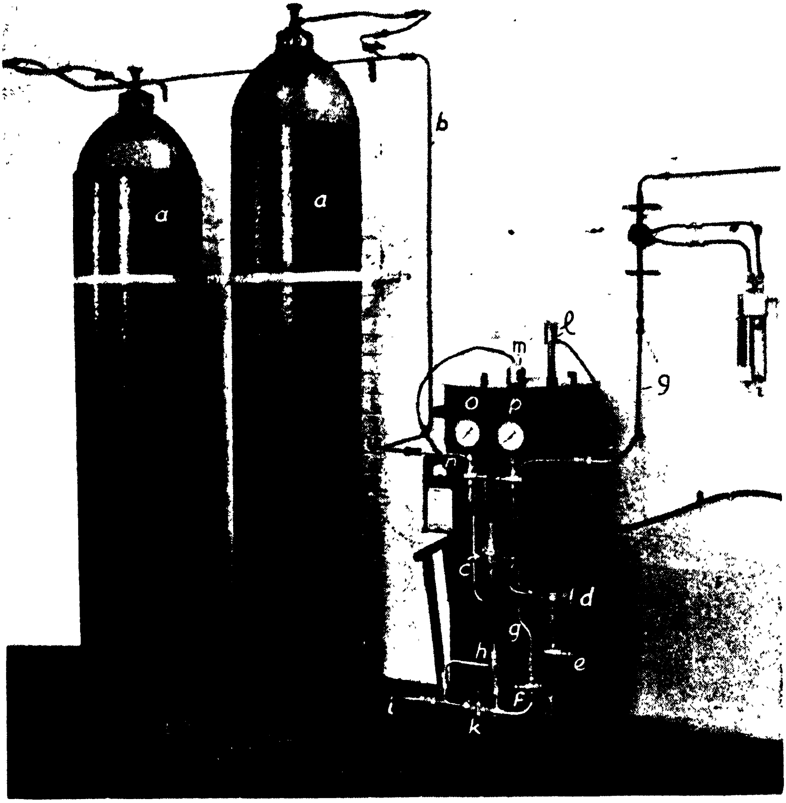


Fig. 8.21. Ammonia Cracker (*I.C.I.*)

and shutting it in case of the current supply being " off ", thus preventing waste of gas.

In order to protect the operator, as mentioned previously (see page 68), the above contactor arrangement makes the electrodes only alive either when the operator uses his free hand, which does not hold the torch, for pressing button *f*, or when the arc is struck.

Hydrogen plant. An ammonia cracker (Fig. 8.21)[1] is often employed for producing the hydrogen used in atomic hydrogen welding (see page 69).

---

[1] Imperial Chemical Industries Ltd., Billingham Division, who have kindly provided the illustrations of the ammonia cracker, draw attention to the fact that the photo (Fig. 8.21) is intended to be an explanatory illustration only, as usually the ammonia cracker is not placed so close to the ammonia cylinders which, if of the large type illustrated, are normally half-submerged in flowing water in a cylinder pit, and placed within reach of a crane or runway. Moreover, the ammonia cylinders can be located as convenient, preferably for direct access by lorry, and up to 200 feet away from the ammonia cracker.

From the ammonia cylinders *a* the gas passes through pipe *b*, pressure-regulating valve *c*, flow control valve *d*, and cracker-isolating cock *e*, into an electrically-heated preheating coil of tubes. The preheated gas then reaches the catalyst tubes which, by means of a thermostat-controlled electric heater, are kept at a temperature of 520–530°C. In these tubes the gas is fully dissociated. After passing through a cooling coil of tubes, the cracker gas arrives at delivery cock *f* and the pipe connection *g* with the welding torch.

In case of excess pressure, a safety valve *h* protects the apparatus by allowing the gas to escape to atmosphere (pipe *i*). Surplus gas or air pockets can also be let off to atmosphere through hand-operated cock *k*. The temperature, controlled by thermostat *l*, is measured through thermocouple *m* on millivoltmeter *n*. The initial pressure of the incoming anhydrous ammonia is measured on pressure gauge *o*, the reduced pressure (reducing valve *c*) on pressure gauge *p*.

CHAPTER IX

ELECTRICAL EQUIPMENT FOR RESISTANCE WELDING

Transformer Equipment. Single phase A.C. transformers are generally used. In case of three phase supply they are usually connected between two phases. This may cause, however, unbalanced loads on the supply line, especially in the case of high powered machines.

In certain cases it may be possible to group several resistance welding machines across phases[1] at approximately equal loading per phase, in order to balance to a certain degree the load on the supply line. Various connections are recommended, but complete balancing can rarely be obtained, as the welding machines are operated neither simultaneously nor at equal or theoretically calculated loads.

This difficulty may even come to the point that in certain areas where power supply facilities are limited the supply authorities may not grant permission to install large projection or flash-butt welding machines, in view of the very high powers used on machines of the most modern types. For example, up to 1200 k.v.a. transformers have been used for the heaviest flash-butt welding machines. An average spot welding machine (e.g. Fig. 4.2) has, however, only a capacity of 60 k.v.a., and should not create any supply difficulties at all.

The transformers themselves differ from the standard types in so far as they are not continuously operated at their normal rating, but are subject to very high current impulses, often large overloads, at short intervals. Due to the large mechanical forces created by such overloads, resistance welding transformers have to be of great mechanical strength and rigidity. The high secondary currents at low voltages require large cross sections of the secondary winding.

The lengths of conductors between transformer and electrodes or clamps have to be kept as short as possible in order to reduce to a minimum the drop in the already low welding voltage.

With regard to the electric power requirements of resistance welding machines, the relation between k.v.a. demand and overall dimensions of the machine is important. Whilst the welding current required for welding a certain thickness of a particular material is constant, the secondary voltage required to obtain that current depends upon the impedance of the secondary circuit. Two welding machines of different size but of equal current capacity will have a different maximum k.v.a. demand. An example is quoted[1] of spot welding together two mild steel pieces, plate thickness ·036″, for which a current of 9000 amps. was used for a duration of 6 cycles. The voltage required in the secondary circuit of a machine having a throat depth *x* (see Fig. 4.2) of 18 inch and a gap between the two arms of 10 inch was 3 volts. This meant a demand of 27 k.v.a. A machine used for the same purpose but with a throat depth of 30 inch and a gap between the arms of 12 inch would, however, require a secondary voltage of 10 volts, thus increasing the demand to 90 k.v.a. The electrical efficiency of the larger machine, when used to do small size work is, therefore, lower than that of the smallest possible machine for the job. This point has to be borne in mind when installing new machinery, and when considering larger size machinery than actually required, in view of possible future work of larger overall dimensions. The machine shown in Fig. 4.2. has an adjustable knee-type bracket supporting the bottom electrode. This allows for better efficiency in case of small size components, when the gap between the arms can be narrowed. An experiment with a similar machine has shown that at equal k.v.a. demand a maximum welding current of about 20000 amps. could be obtained with the smallest possible throat area, whilst a maximum current of only about 12000 amps. could be obtained with the largest possible throat area.

---

[1] See C. A. Burton, "The Power Supply, Installation and Servicing of Resistance Welding Machines," *Sheet Metal Industries*, November 1945.

To improve the very unfavourable loading conditions imposed on the supply when applying very high welding currents at short welding times (e.g. welding of light alloys, see page 124) *energy storing equipment* is often employed. Either magnetic or condenser energy storage equipment is used.[2] The former stores the energy in an inductor transformer, with a D.C. of 100–400 amps. in the primary winding. When this current is interrupted by a magnetic contactor a high current impulse (lasting 0·01–0·05 sec.) occurs in the secondary (welding) circuit. In the condenser energy storage equipment, the energy required for welding is stored in a bank of static condensers which are charged to a voltage of 1000–3000 volts. To initiate the welding operation this bank of condensers is connected to the primary of a welding transformer, creating a sudden impulse of high welding current in the secondary (welding) circuit.

Both the above types of equipment impose upon the supply line only about 10 per cent of the load which would be caused by ordinary transformer equipment for obtaining equivalent welding currents.

[1] C. A. Burton, "The Power Supply, Installation and Servicing of Resistance Welding Machines," *Sheet Metal Industries*, November, 1945.

[2] See *Resistance Welding Manual*, published by the Resistance Welder Manufacturers' Association, Philadelphia, Pa., U.S.A.

Timing Devices are divided into two main groups[1]: *Non-synchronous timers* which start and interrupt currents at any time without relation to the voltage wave, and *synchronous timers* which always start and interrupt the currents at exactly the same point of the voltage wave, and which are, therefore, ensuring high accuracy in the current wave form and in the energy delivered for each welding operation.

The simplest timing device is a spring- or solenoid-operated contactor, the operation of which is delayed by an air or oil dash pot. The accuracy obtained with this type of equipment is, obviously, not of the highest degree.

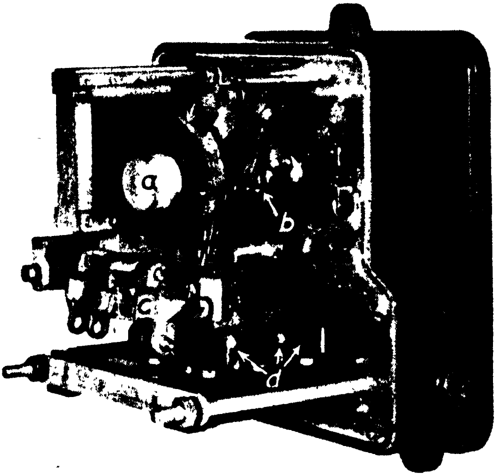


Fig. 9.1. Electro-mechanical Timer (*B.T.H.*)

The electro-mechanical timer (Fig. 9.1) for time intervals varying from 5 seconds for the fastest type to 20 minutes for the slowest type, consists of driving motor, speed-reducing and timing gear, switch contacts, and operating solenoid. After being energized by any form of switch in the circuit, the solenoid actuates a clutch connecting the running motor with the timing cam. The time interval is adjusted by setting the timing cam (knob *a*), and the operation is completed when the cam raises a spring catch *b*. This releases the contact-operating bar *c* which in turn opens or closes the contacts *d* as required. The

[1] See *Resistance Welding Manual*, published by the Resistance Welder Manufacturers' Association, Philadelphia, Pa., U.S.A.

timer resets immediately the clutch solenoid is de-energized. The accuracy of the timing operation depends upon the speed accuracy of the driving motor and the inertia and friction in the contact mechanism.

Highest timing accuracy is obtained by employing *electronic control* equipment. A short description of the control valves used in such devices will facilitate the understanding of their operation.

The hot cathode *thyratron* (Fig. 9.2) is a three electrode valve which consists of a glass bulb containing an anode, a cathode, and a control grid (Fig. 9.3). The glass bulb is exhausted to a high degree of vacuum, and is filled with a partial atmosphere of vapour or inert gas. Mercury vapour is generally employed, and inside a cold thyratron a small drop of mercury can be seen, which during operation is vaporized.

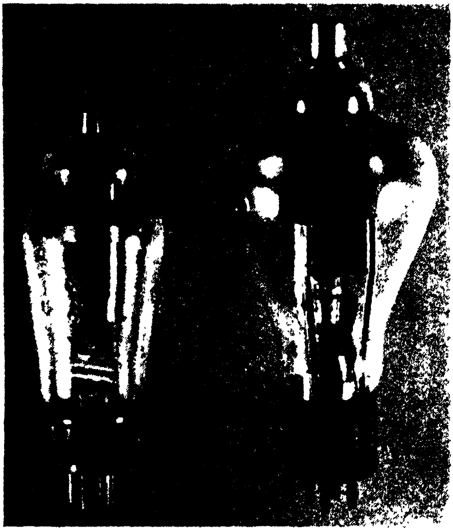


Fig. 9.2. Thyratrons (*B.T.H.*)

The anode is normally maintained at a positive potential with respect to the cathode, which is coated with substances having high electron emissivity when heated. Before operations the cathode is heated to the temperature necessary to ensure a sufficient flow of electrons and to raise the temperature of the valve to a point at which vapour pressure is sufficient for current conduction. Direct or indirect heating is employed. In the former method a current is passed through the cathode itself, in the latter method the current is passed through its heater.

Current must not be passed through the thyratron until the cathode has attained its correct operating temperature, as otherwise damage will result. For this purpose time-delay devices are usually fitted.

If the electric field between the positive anode and the cathode has sufficient intensity, the negatively charged electrons leaving the cathode will be attracted to the anode and will attain sufficient velocity to cause ionization of the mercury vapour. The positive ions flow towards the cathode and neutralize the space charge effect of the electrons leaving the cathode. In this condition an arc is formed between anode and cathode, and current will flow through the valve and its external anode circuit.

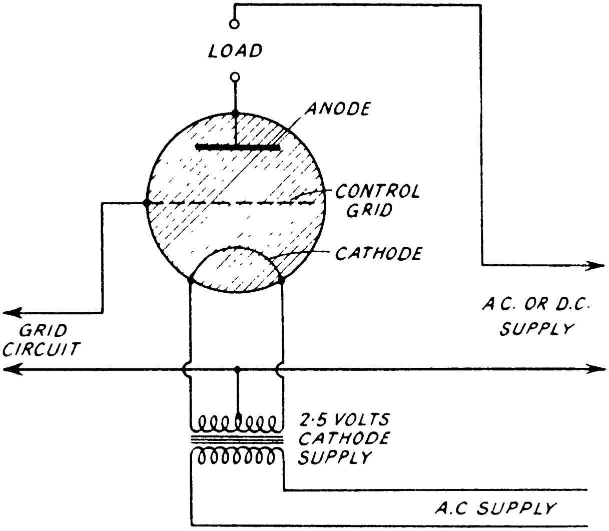


Fig. 9.3

This flow of current through the valve depends, however, upon the condition of the control grid. In the simple type of thyratron this consists of a perforated plate through which the electron stream passes. If the grid voltage is more negative than a certain critical value, with respect to the cathode, the negatively charged electrons will be repelled by the negative field of the grid, and conduction cannot take place. If the grid is now made more positive and passes the critical value, the valve becomes conducting.

Once the grid has allowed conduction to commence, it has no further control over the arc under normal conditions. In the condition of ionization positive ions are attracted to the negative grid, surrounding it by a sheath which neutralizes its field and destroys its control action. The only means of interrupting the current is by the reduction of the anode voltage, thus reducing the electric field set up between anode and cathode to such an extent that ionization is not maintained. The critical anode voltage is called the ionization potential and depends upon the gas or vapour filling of the tube.

Current interruption can, therefore, be achieved either by switching off the anode voltage by means of an external switch, or by supplying the anode with an alternating voltage.

With an alternating anode voltage the thyratron will be conducting during the positive half-cycle, but will shut off as the anode potential approaches zero volts and passes into the negative half-cycle. If the grid voltage is returned to cut-off value, the valve will not restrike when the anode voltage rises at the next positive half-cycle. This method of control is known as "on–off" control.

Another method of thyratron control is phase control, by which the mean value of anode current can be varied as required through controlling the phase of the grid voltage, the grid voltage being synchronous with the anode voltage.

Fig. 9.4 shows oscillograms of the anode and grid voltages of a pair of trigger thyratrons controlling an ignitron contactor (see page 170) to provide heat control for welding machines. At (1) is shown the anode-cathode voltage of the two thyratrons firing at alternate half-cycles. The grid is supplied with a voltage consisting of four different components which are shown at (2), (3), (5) and (6). At (2) is shown the *hold off voltage sine wave component* which is 180° out of phase with the anode voltage. This combines with the *hold off voltage decaying D.C. component* at (3) to form the total hold off component shown at (4). The D.C. component ensures that a standing negative grid voltage exists when the anode volts are zero and going positive.

The *firing voltage sine wave component* is shown at (5). It is in phase with the anode voltage and is, therefore, positive when the anode voltage is positive.

The *firing voltage peaker component* is shown at (6) and (6A). This voltage is obtained from the secondary winding of a "peaker" transformer. It is positive when the anode voltage is positive, can be shifted in phase, and can occur anywhere between 45 degrees and 135 degrees. By itself this voltage is unable to overcome the total hold off voltage, as shown at (7).

When, however, the four components are combined as shown at (8), the negative grid voltage is reduced, and the thyratron becomes conducting.

Thus, the firing voltage sine wave component determines the number of cycles during which the thyratron will conduct, and the firing voltage peaker component determines at which point in each cycle

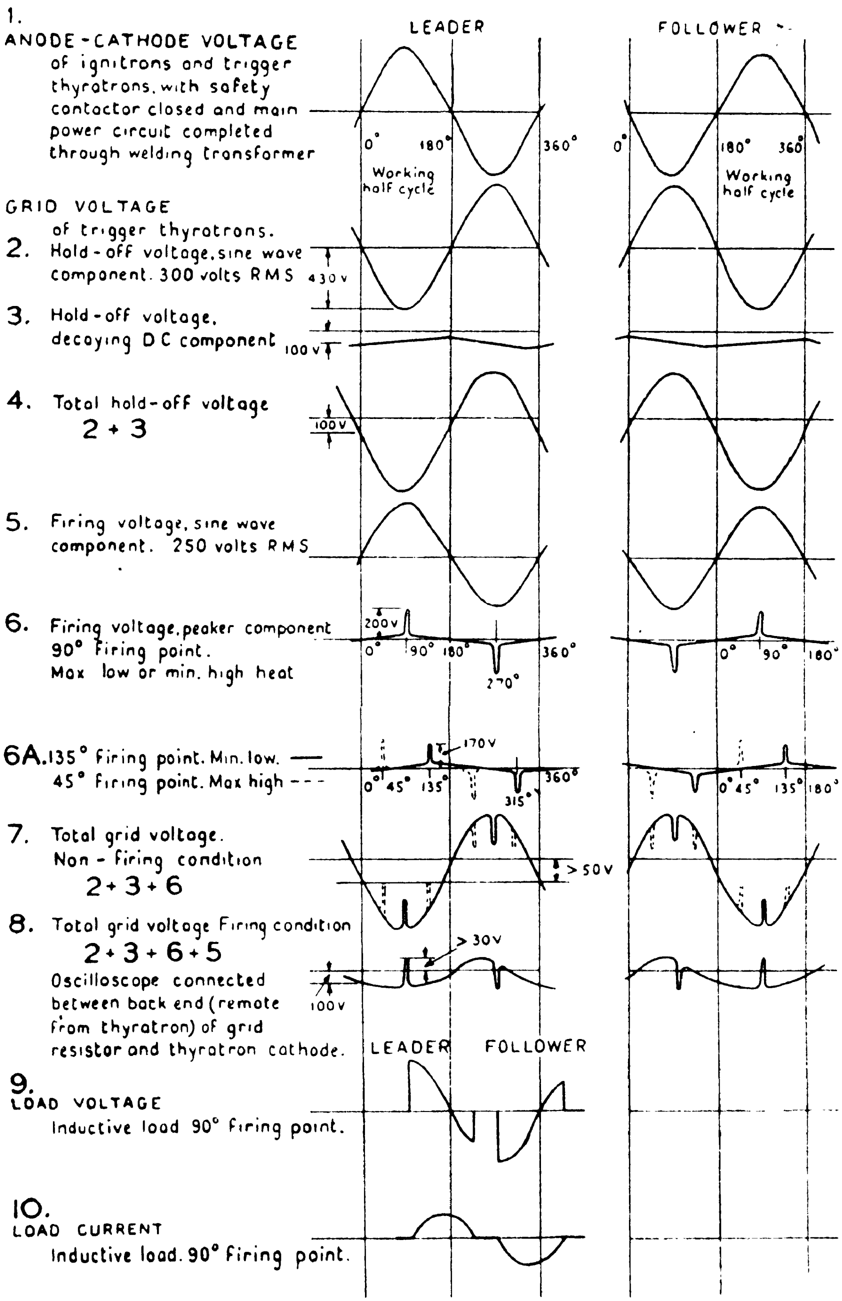
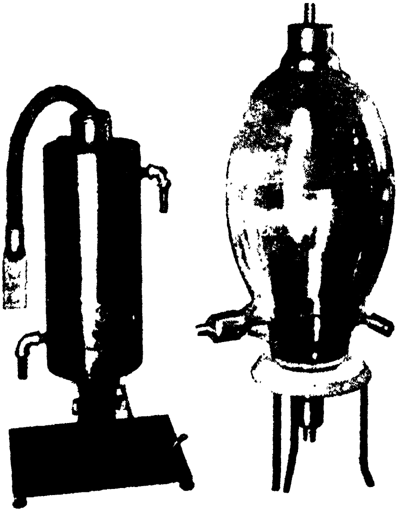


Fig. 9.4. Oscillograms of Ignitrons and Trigger Thyratrons to show functioning of heat control by phase shift. (*B.T.H.*)

current will commence to flow. A practical example of this method of control applied to welding machines will be illustrated later (see page 179).

From the foregoing it can be seen that the thyratron acts as a relay which can be accurately controlled, and which is virtually instantaneous in operation, due to the absence of moving parts.

The ignitron (Fig. 9.5) consists of a glass or metal envelope containing two electrodes and an igniter. The electrodes are the anode (*a*, Fig. 9.6), normally made from a material which does not emit electrons freely, such as graphite, and the mercury pool cathode *b*. The igniter *c* is made from a semi-conducting material and is partially immersed in the mercury pool *b*. Metal-clad ignitrons (Fig. 9.5 A) are normally water-cooled (water jacket *d*, Fig. 9.6), and glass bulb ignitrons (Fig. 9.5 B) are normally fan-cooled.



A B

Fig. 9.5. Ignitrons (*B.T.H.*)

Operation is initiated by passing a current through the igniter. This forms a hot spot at the surface of the mercury pool from which electrons are given off. If the potential of the anode is positive and sufficiently high, with respect to the cathode, an arc is struck and anode current commences to flow. If the anode is connected to an alternating current supply, current will only flow during the positive half-cycle when the anode voltage is positive with respect to the cathode. Thus the current in the anode circuit consists of a series of uni-directional pulses. For resistance welding transformers alternating current is required, and to obtain this two ignitrons are connected in reverse parallel as shown in Fig. 9.6. Once the arc has been struck and anode current flows, the igniter has no further control over it, until the anode potential approaches its next zero at the end of a positive half-cycle. Then the arc is extinguished, the interelectrode space is de-ionized, and the igniter has to restrike the arc at the next positive half-cycle. The arc can be initiated at any point in the positive half-cycle by control of the igniter current.

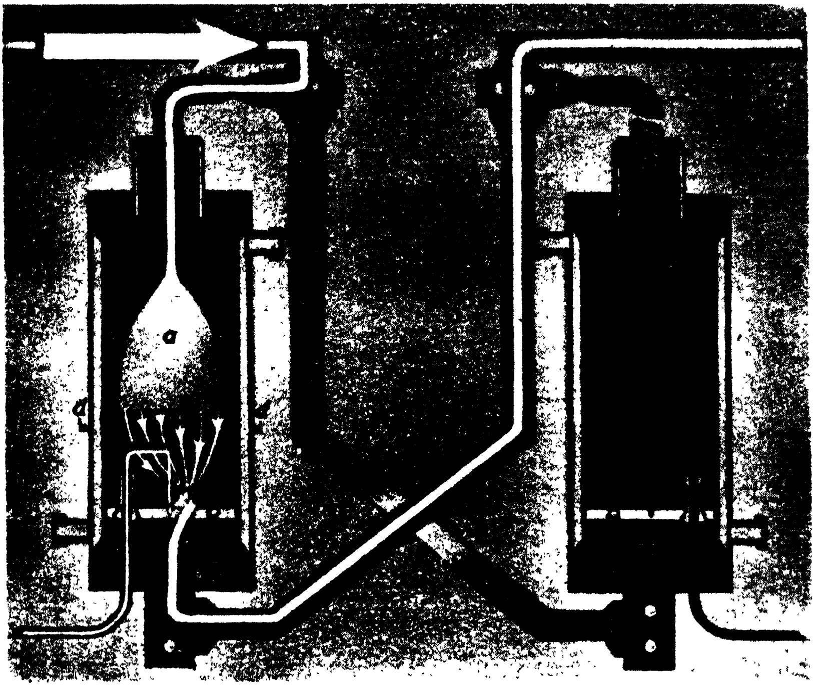


Fig. 9.6. The Functioning of Ignitrons (*B.T.H.*)

The ignitron is capable of handling large currents within certain limitations which are related to the voltage, temperature of the ignitron and vapour pressure, the latter depending upon the mean current value.

Fig. 9.7 shows diagramatically the arrangement of the ignitron contactor (Fig. 9.8). (L_1) and (L_2) are two ignitrons connected in reverse parallel, each having its igniter circuit shunted by a metal rectifier (4,5). The protective water-flow switch (1) has normally open contacts which are closed when an adequate supply of cooling water flows to the ignitrons.

A timing circuit is connected between terminals (2–3). This may be of any form, but an electronic circuit is preferable in the interest of accurate control.

The function of the two rectifiers (4) and (5) is to limit reverse current flow through the igniter circuits of the ignitrons.

Assume that the anode a_1 of ignitron (L_1) is positive, and it is required to fire this ignitron. On closing the mains switch current will flow through the welding transformer and up to the cathode b_2 of (L_2). Here the current will divide, a small reverse current flowing through the igniter c_2 circuit of (L_2) (resistance 7), and the major portion of the current flowing through the rectifier (5), fuse (8), the timing device (terminals 2–3), the water-flow switch (1), and the fuse (9) to the junction of resistance (6) and rectifier (4). The current divides again at this point, a small reverse current to the cathode b_1 through the rectifier (4) in a backward direction, and a heavy current to the igniter c_1, through the mercury pool cathode b_1 to the supply line 2. Ignitron (L_1) thus fires and passes load current.

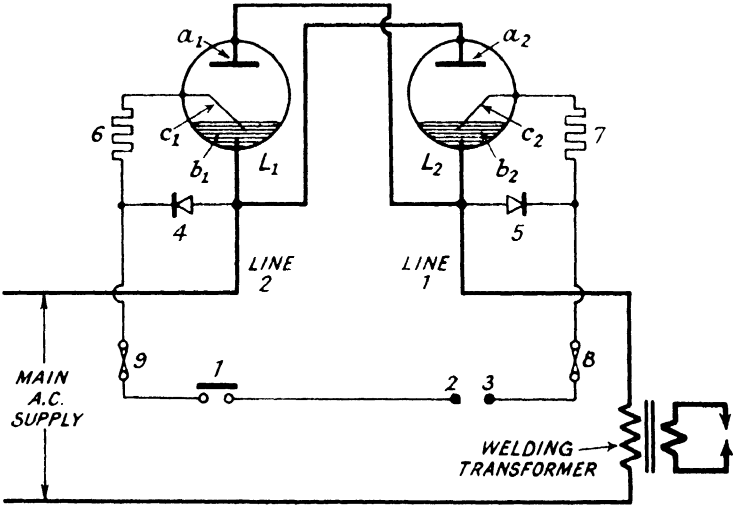


Fig. 9.7

When the current in (L_1) ceases to flow, the anode a_2 of (L_2) will be positive due to the inductive nature of the load, and (L_2) will fire. The ignitrons will continue to fire alternately until they are shut down by the control circuit.

The advantages of ignitron contactors over electromagnetic types are their capability of more rapid operation, and their greater k.v.a. capacity. In order to initiate an operation, a voltage is necessary at the igniter, and the ignitron will not fire at voltage zero where current transients are likely to be present in the power circuits. When used in a resistance welding machine the ignitron contactor produces more consistent welds than the electromagnetic contactor which may initiate welding at voltage zero.

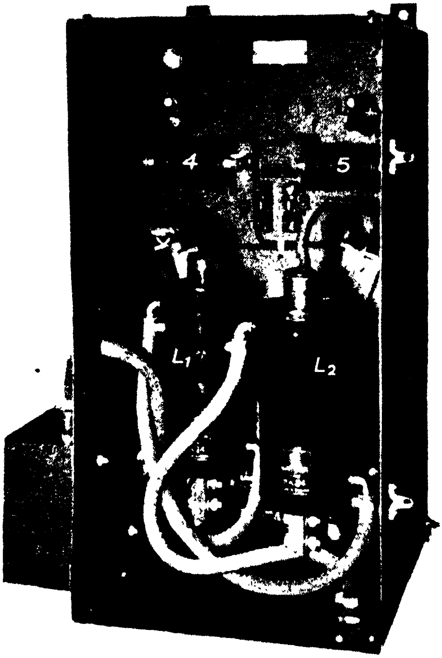


Fig. 9.8. Ignitron Contactor (*B.T.H.*)

The charging or discharging time of a *condenser* depends upon the resistance of the condenser circuit, and the discharge rate can be controlled by variation of this resistance. In welding timers of the condenser charge type this action is used to obtain control of the welding time. An example is the thyratron contactor timer as used in spot welding machines.

In this timer a condenser is used to supply the grid voltage to a

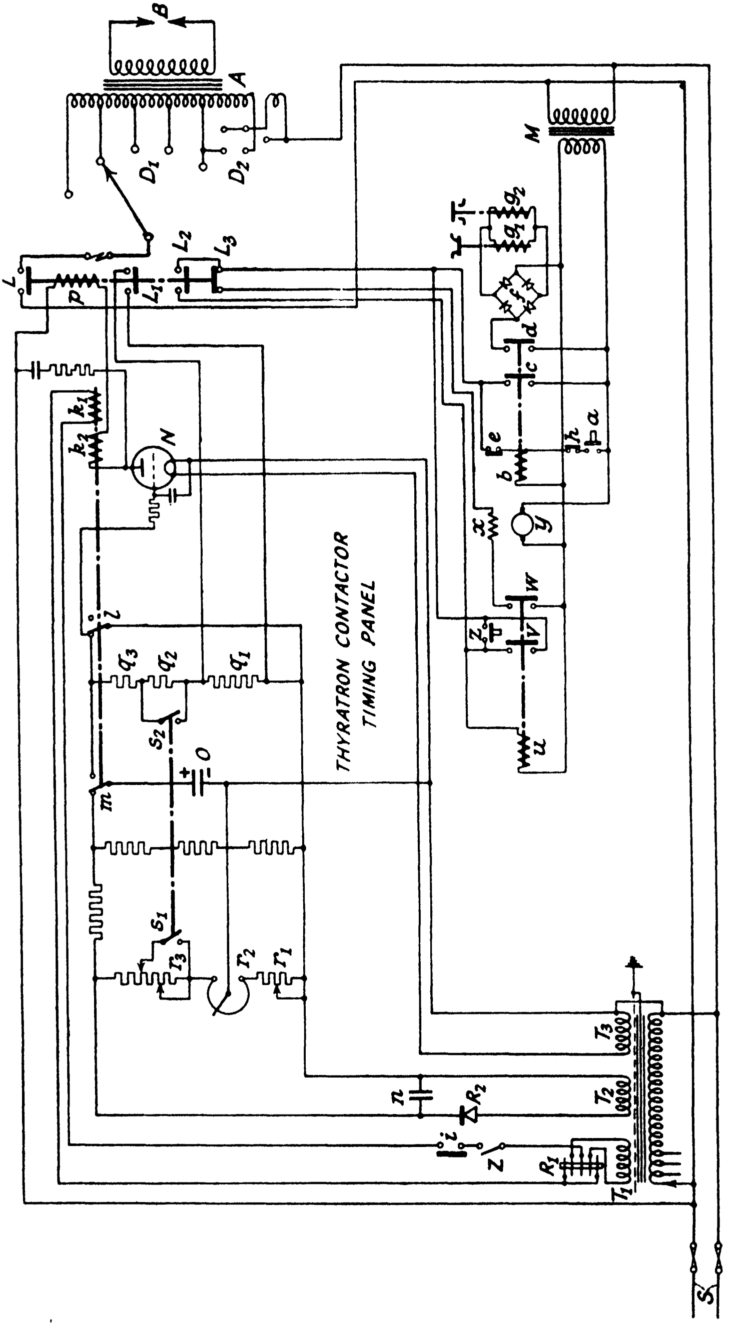


Fig. 9.9. Spot Welder Circuit Diagram (*Metropolitan-Vickers*)

control thyratron which operates by the " on–off " method of control previously described (see page 168).

A schematic diagram of a spot welding machine circuit with thyratron contactor time control is shown in Fig. 9.9.

The welding transformer A (see also Figs. 4.2 and 9.10) supplies the heavy welding currents to the electrodes (B) at suitable low voltage.

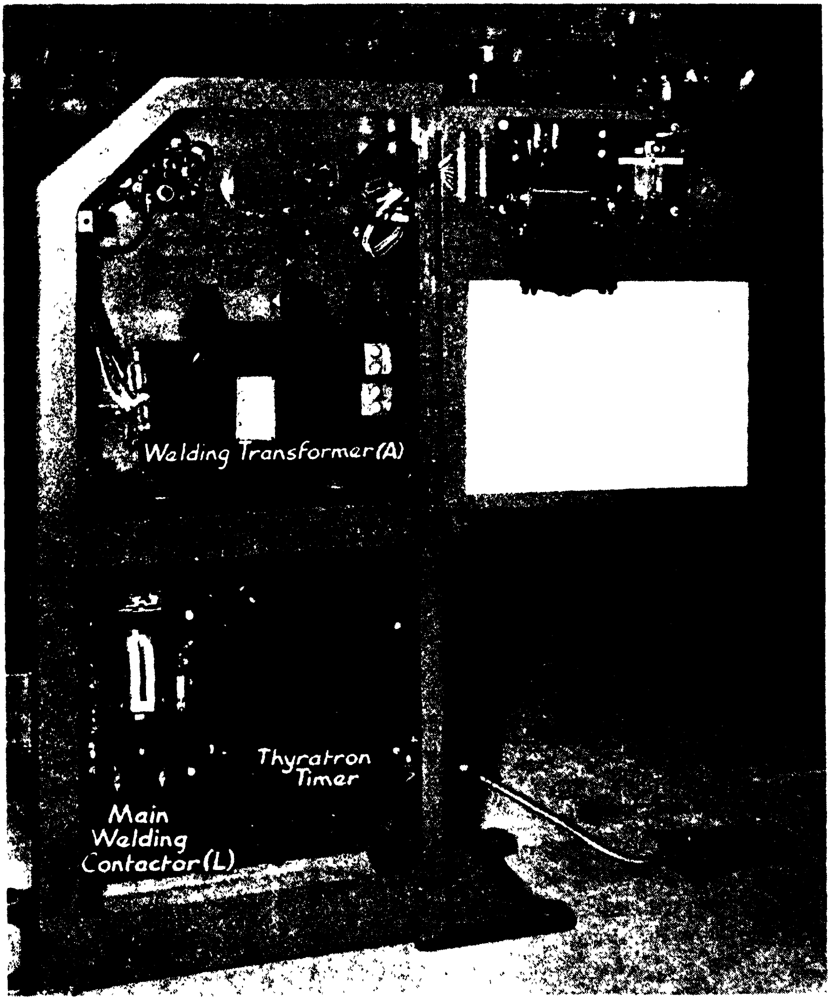


Fig. 9.10. View of Controls of Spot Welder (see Fig. 4.2)
(*Metropolitan-Vickers*)

The current is adjusted by means of the tapping switch (D_1) and the series parallel switch (D_2) in the transformer primary. The welding current is controlled by the main contactor (L) in the primary circuit.

The control circuit is divided into two parts, one controlling the actual welding time, i.e. the time during which the main contactor (L) is closed and current is flowing through the electrodes and the work, the other controlling the forging time, i.e. the time during which pressure is still applied to the work after main contactor (L) has opened and current has ceased to flow.

The welding time is controlled by a thyratron contactor panel fed by transformer T_1, whilst the forging time is controlled by an electro-mechanical timer (see page 165) fed by transformer M.

The operator initiates the welding operation by closing foot switch *a*, thus energizing coil *b* and closing relay contacts *c* and *d*. Contacts *c* are maintaining contacts for the circuit controlled by foot switch *a*, and hold coil *b* energized, even if the foot switch is opened. Coil *b* holds contacts *c* and *d* closed so long as the mechanical timer contacts *e* remain in the normally closed position.

Contactor *d* closes the circuit of bridge rectifier *f* thus energizing solenoid coils g_1–g_2 which operate the air supply valves. The two coils g_1–g_2 are connected in parallel and, when energized, operate simultaneously on the two air valves. The valve operated by g_1 is normally closed and, when opened, connects the compressed air supply with the top of the pressure cylinder (C, Fig. 4.2), the valve operated by g_2 is normally open and connects the compressed air supply with the bottom of the pressure cylinder (C, Fig. 4.2).

When the two valves are operated, air flows into the top of the pressure cylinder, and the top electrode closes down on to the work with a predetermined pressure set by the pressure-regulating valve (see G, Fig. 4.2). As it travels downwards, the top electrode opens limit switch *h*, thus preventing a further operation by means of the foot switch, until the top electrode returns to its starting (top) position.

As soon as the full welding pressure is reached, pressure switch *i* in the thyratron control circuit is closed, and the timing cycle is initiated. Coil k_1 is energized from transformer secondary (T_1), through selenium rectifier (R_1) and switches *l* and *m* are moved across to the right-hand contacts.

The main supply having been switched on before the above operation commenced, the cathode of the thyratron has been heated up to the required temperature (transformer T_3), and the condenser *o* has been charged up (transformer T_2, rectifier R_2). Before the switches *l* and *m* are changed over by coil k_1, the condenser is connected to the D.C. positive line (rectifier R_2) by switch *m*, and the thyratron grid is held negative by switch *l*. When the switches *l* and *m* change over, the condenser is disconnected from the positive line and is connected (switch *m*) to the thyratron grid which has been disconnected (switch *l*) from the D.C. negative line by simultaneous operation. The thyratron grid is now positive, and current flows through the thyratron, coil k_2, and coil *p* of the main contactor, thus closing the main contactor (L), auxiliary switches L_1 and L_2, and opening auxiliary switch L_3. Coil k_2 acts as maintaining coil to switches *l* and *m*, and ensures that these switches remain in the right-hand position until the thyratron has ceased conducting and the operation is satisfactorily completed, even if pressure switch *i* opens prematurely.

The rate of discharge of condenser *o* is controlled by variable resistances r_1 and r_3 and rheostat r_2. The discharge rate is accelerated by shorting out resistance q_1 by means of auxiliary contacts L_1. When the condenser has discharged to the critical grid voltage of the thyratron, current flow ceases, and the supply to coil *p* is interrupted, the contactor opens, and the welding current is shut off. The welding time depends upon the position of the slider of rheostat r_2. The nearer the slider is to the D.C. positive, the sooner will the thyratron grid become negative with respect to the cathode, and the shorter will be the welding time. Very short welding times are provided by short circuiting resistance q_2 and a portion of r_3 by means of switches s_1 and s_2.

While switch *i* remains closed, and coil k_2 maintains switches *l* and *m* in the right-hand position the panel is prevented from resetting for a further operation.

At the commencement of the above welding cycle, when auxiliary switch (L_2) is closed, coil *u* is energized and contacts *v* and *w* are closed. Contact *v* is a maintaining contact and keeps switches *v* and *w* in the closed position.

Switch *w* is in the circuit of coil *x* which is energized at the end of the welding cycle, when the normally closed auxiliary switch (L_3) returns to its normal position. Coil *x* operates the clutch solenoid of the mechanical timer, whose motor *y* has been running continuously, being directly connected to the 110-volt supply of the control circuit, and the timing of the forging operation commences.

After a time delay, controlled by the mechanical timer (E_3, Fig. 4.2), the timer cam trips switch *e* which opens the circuit to coil *b*. Coil *b* is de-energized, even if the operator has kept the foot switch closed, as limit switch *h* is maintained open as long as the top electrode is down. With coil *b* de-energized, contacts *c* and *d* open; when contact *c* is opened coil *u* is de-energized, and contacts *v* and *w* open, and when contact *d* is opened the coils g_1 and g_2 are de-energized, and the air control valves return to their normal position. Air pressure is now applied to the bottom of the pressure cylinder, the top electrode rises, and the welding and forging operations are complete. As the pressure falls, switch *i* is opened, and as the top electrode rises, limit switch *h* closes, and the equipment resets for further operation.

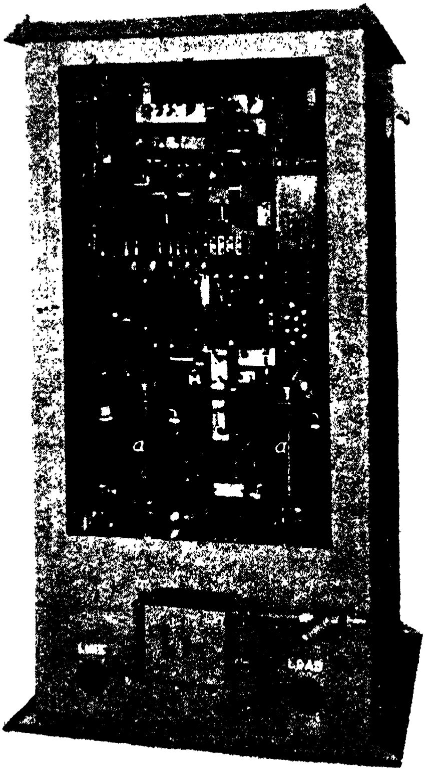


Fig 9.11. Ignitron Contactor Panel (*B.T.H.*)
a, *a*, ignitrons. *b*, water-flow switch

During setting operations it is often desirable to operate the electrodes only, without applying welding current. For this purpose "on–off" switch (Z) can be opened by hand in order to isolate the timing circuit from transformer secondary (T_1). The electrodes can now be closed by means of foot switch *a*, and no welding current will flow. In order to return the top electrode to the upper position after setting, resetting push button switch *z*, which is connected in parallel with auxiliary contacts (L_2) and contact *v*, is used, and the forging control-circuit operates as during normal welding operation.

Accurate and synchronous timing is essential when materials are to be welded whose plastic range is narrow, like many non-ferrous metals. It is also of great importance in all cases where the total welding time is very short, e.g. a few cycles, so that small differences would represent a large percentage of error. Electronic controllers consisting of ignitron contactors controlled by thyratrons have been developed to perform a great variety of welding operations and duties (Fig. 9.11). Single spot or projection welding operations, continuous seam welding operations, pulsation welding operations with the welding current interrupted and re-started at predetermined intervals, and with variable current intensity, are successfully controlled by electronic devices. One important application of electronic control is that of current control by phase shifting methods previously described (see page 168).

The following diagrams illustrate the application of electronic controls to spot and seam welding machines.

Fig. 9.12 shows schematically the circuit of a spot welding machine with an ignitron contactor, controlled by a thyratron timing panel and a phase shifting heat control panel.

The electrical and water supplies are switched on, and after a time delay of approximately 10 minutes the time delay switch pulls in, safety switches (S_2) can now be closed, and the equipment is ready for operation.

The timing of the equipment depends upon the charging rate of a resistance capacity circuit, the charging of this circuit being in turn controlled by the timing thyratron *a*. The grid of the leading control thyratron *b* is normally held negative with respect to its cathode by the voltage between the slider of rheostat (R_3), connected to the grid, and the D.C. positive connected to cathode. Thyratron *b* is thus held non-conducting.

To initiate a weld, the foot switch is closed and switch (S_1) is pulled across to the left-hand position by its operating coil. This closes the anode circuit of thyratron *a* and applies anode potential. Thyratron *a* is held non-conductive by a negative grid voltage derived from (R_4) which forms part of the potential divider across the D.C. supply. When the next positive peak occurs across the secondary of transformer (T_1) the negative grid voltage is overcome and thyratron *a* will conduct.

At this instant the grid of thyratron *b* will become positive with respect to its cathode, since the cathode is carried negatively from the potential of the D.C. positive to about 15 volts positive with

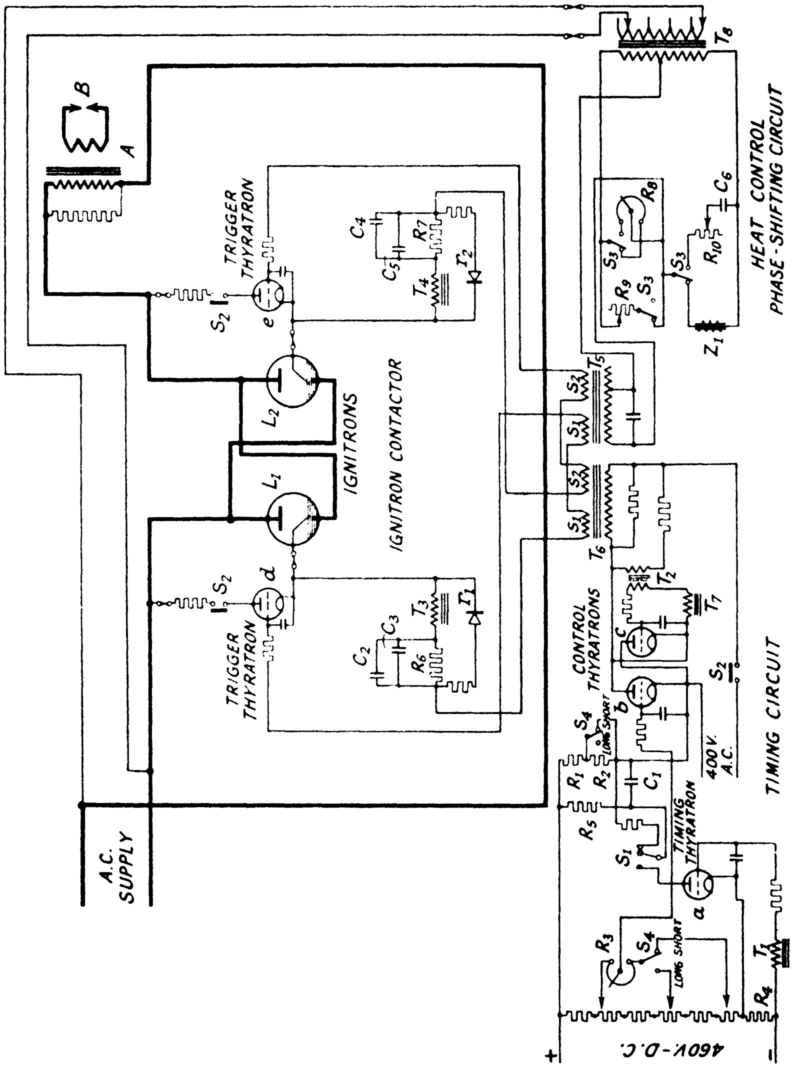

A.C. SUPPLY
A
B
TRIGGER THYRATRON
S_2
e
TRIGGER THYRATRON
S_2
d
L_1
L_2
IGNITRONS
IGNITRON CONTACTOR
C_2
C_3
R_6
T_3
r_1
C_4
C_5
R_7
T_4
r_2
T_5
T_6
S_1
S_2
S_1
S_2
T_8
R_8
R_9
S_3
S_3
S_3
R_{10}
C_6
Z_1
HEAT CONTROL PHASE-SHIFTING CIRCUIT
CONTROL THYRATRONS
c
b
T_2
T_7
S_2
400V. A.C.
S_4
LONG SHORT
R_1
R_2
C_1
R_5
S_1
TIMING THYRATRON
a
R_3
S_4
LONG SHORT
T_1
R_4
+
460V.-D.C.
−
TIMING CIRCUIT

Fig. 9.12

respect to the cathode of the timing thyratron *a*; the anode voltage of thyratron *b* is arranged to be negative at this instant. Condenser (C_1) will commence to charge up, and, as the grid of thyratron *b* is positive, thyratron *b* will conduct as soon as its anode voltage becomes positive during the next half-cycle.

When condenser (C_1) has charged up sufficiently, the grid of thyratron *b* becomes negative with respect to its cathode, and at the succeeding negative half-cycle of the anode voltage, the thyratron ceases to conduct.

The charging time of the condenser (C_1) is controlled by rheostat (R_3), and by the amount of charging resistance in the circuit as set by range switches (S_1).

When condenser (C_1) is fully charged, the flow of charging current through thyratron *a* ceases, the timing thyratron remains conducting through the resistance (R_5) which is in parallel with the charging circuit. This ensures accuracy of anode voltage in respect to the potential divider with consequent accurate operation.

Thyratron *c* called the follower thyratron is made conducting by the voltage across the secondary of transformer (T_2). This voltage results from thyratron *b* conducting, and it overcomes the hold-off voltage provided by the secondary of transformer (T_7). Thus the control thyratrons, which are connected in reverse parallel will conduct during alternate half-cycles.

When the weld is complete the relay coil of switch (S_1) is de-energized, and the switch returns to the right-hand position, discharging condenser (C_1) and resetting the equipment for further operation.

The ignitrons (L_1) and (L_2), in the primary circuit of the welding transformer are controlled by the trigger thyratrons *d* and *e*.

The grid voltages of these two thyratrons are built up of four components (see page 168):

1. A.C. hold off voltage, sine wave component.
2. Decaying D.C. negative component.
3. Firing voltage, peaker component.
4. Firing voltage, sine wave component.

These components form the timing and heat control of the equipment as previously described, and they are obtained as follows:

1. The A.C. hold-off voltage, sine wave component is supplied by the secondary windings of transformers (T_3) and (T_4). This voltage is 180 electrical degrees out of phase with the respective trigger thyratron anode voltage.

2. The decaying D.C. component (rectifiers r_1 and r_2) appears

across resistances (R_6) and (R_7). In parallel with these resistances are connected condensers (C_2), (C_3) and (C_4), (C_5). During the half-cycle in which the thyratron anode voltage is negative these condensers charge up, and during the ensuing positive half-cycle they discharge to give a decaying D.C. component across the resistance R_6 and R_7.

3. The firing voltage "peaker" component is supplied by the secondary winding s_1 and s_2 of transformer (T_5). The secondary windings produce a voltage of peaked wave form.

The peaker component can be shifted in phase between 45 and 135 degrees from the voltage zero; i.e. from maximum heat to minimum heat with medium heat at 90 degrees. This shift is achieved by means of the phase-shifting bridge composed of heat control rheostat (R_8) and resistance (R_9) and choke Z_1 for high heat, and rheostat (R_8) resistance (R_{10}), and condenser (C_6) for low heat. The appropriate heat range is selected by means of the range switches S_3.

A phase shift range of about 100 degrees results in a variation in effective current value of approximately twenty to one, which—in case of other welding conditions being constant—means a variation in welding heat of four hundred to one.

4. The firing voltage, sine wave component is supplied by the secondary winding s_1 and s_2 of transformer (T_6). It is in phase with the anode voltage of the thyratron and is, therefore, positive when the anode voltage is positive. This voltage reduces the negative hold-off voltage of the thyratron, and enables the peaker component to fire the thyratron by carrying the grid positive.

The firing voltage sine wave component which is controlled by the timing circuit thus determines the number of cycles during which the trigger thyratrons conduct, and the peaker component determines at which point in each cycle the thyratron fires.

The trigger thyratrons control the current to the igniters of the ignitrons (L_1) and (L_2), and, as the thyratrons conduct, they cause their respective ignitrons to conduct also.

A similar circuit arrangement, as applied to a seam welding machine, is shown in Fig. 9.13.

This circuit operates similarly to that in the spot welding circuit (Fig. 9.12), and the common components have been given the same symbols in order that the two diagrams may be compared. The difference between the two circuits lies in the timing circuit which, in the case of the seam welder, consists of a synchronous chain commutator.

The chain commutator is an endless chain carried between two sprockets and driven by a synchronous motor (Fig. 9.14). Conducting (white) and non-conducting (black) contacts can be fitted to the chain

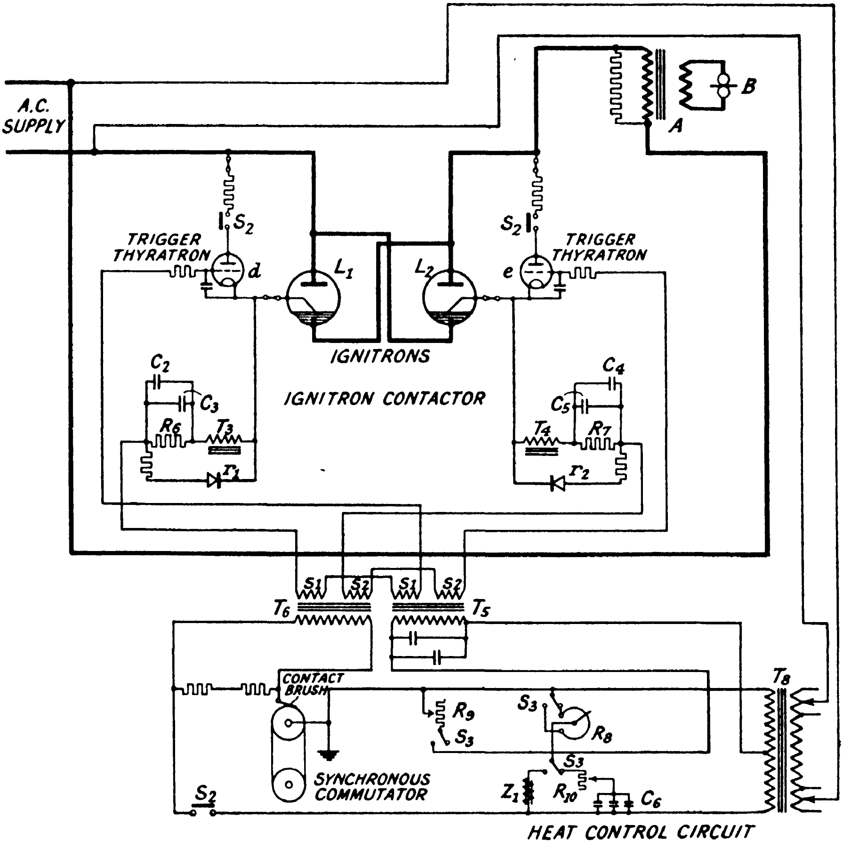


Fig. 9.13

to provide a variety of welding cycles. A fixed brush bears upon the contacts and is connected in the primary circuit of transformer (T_6) which supplies firing voltage sine wave components to the grids of the trigger thyratrons.

By means of the commutator contacts a continuous series of welds can be made, each of a duration depending upon the number of consecutive conducting contacts, each contact representing one half-cycle of supply.

It is essential that no D.C. component appears in the welding current, and precautions to avoid this are necessary when setting up the contacts on the chain commutator. The sum of the "positive" half-cycles in two consecutive welds must equal the sum of the "negative" ones in these same two welds. When the welding time is an equal number of half-cycles the weld is obviously balanced, but if the weld is an odd number of half-cycles it is essential to have an even number of half-cycles of " off " time between welds. This is known as anti-polar starting, because consecutive welds are started on half-cycles of opposite polarity giving the closest approach to pure interrupted balanced alternating current in the welding transformer.

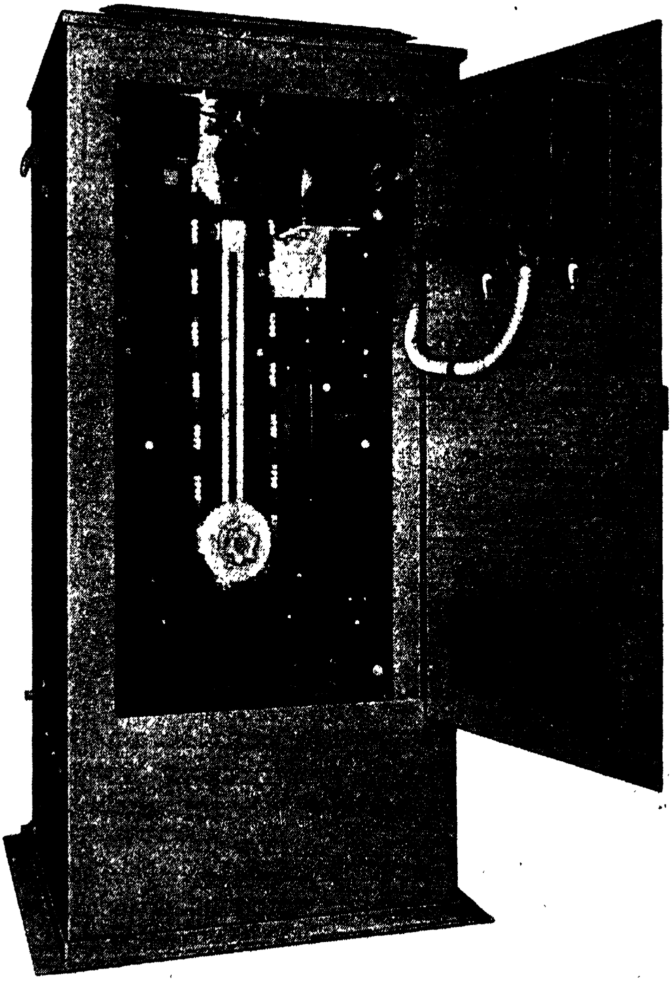


Fig. 9.14. Seam Welder Control Panel (*B.T.H.*)

CHAPTER X

FLAME CUTTING AND GOUGING

Flame Cutting. Among the processes for preparing plate material for welded fabrication, this takes a prominent part. It is applicable to very large thicknesses of material and allows any shape or profile to be cut—two points which restrict the use of guillotines. It is faster than machining operations, which is particularly important in connection with plate edge preparations for welding.[1]

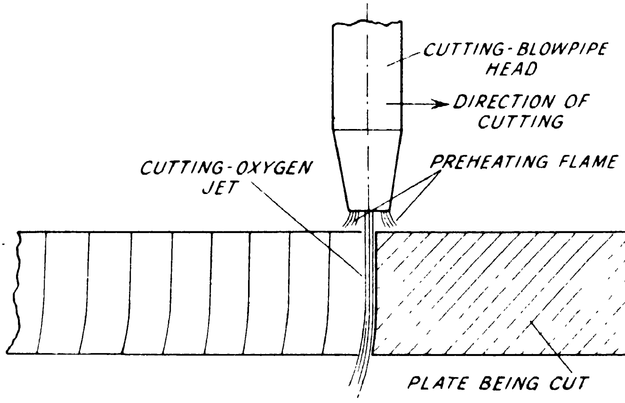


Fig. 10.1

The process (Fig. 10.1) consists of heating the steel plate to combustion temperature (about 900°C.), causing rapid oxidization (combustion) by supplying a jet of pure oxygen, and blowing away the iron oxide thus formed and any molten iron particles under the pressure of the oxygen jet. The heat freed by the chemical reaction helps in the preheating of further portions to be cut, and less heat is required to continue cutting after a start has been made, than is required for starting the cutting operation.

From the foregoing it will be appreciated that only those materials can be flame cut, whose combustion temperature is below their melting temperature, as otherwise the material would melt away before oxidization and a clean-cut edge could not be obtained. It is also important that the melting temperature of the oxides lies below that of the parent material.

---

[1] A comprehensive series of articles on the subject has been published under the title, "Oxygen Cutting," by E. Seymour Semper in *Welding,* between July 1946 and December 1947.

Non-ferrous metals cannot, therefore, be flame cut. Cast iron and stainless steel need special procedures and even then a " flame-cut edge " of the same quality as with steel cannot be obtained (see page 199).

The purity of the oxygen (see page 129) is of great influence upon the efficiency of the process, and an increase of the impurity (mainly nitrogen) content from 0·5 to 1·5 per cent, for example, results in a reduction of cutting speed and such an increase in hourly oxygen consumption, as to raise it by 40 per cent for cutting one foot length of 1″ thick steel plate.[1] The oxygen usually supplied for welding and cutting is guaranteed to contain not more than 0·5 per cent impurity (see page 129).

When the flame-cutting process was originally developed at the beginning of this century, hydrogen was used as fuel gas for the heating flame, but to-day acetylene is the fuel gas most frequently used, especially in welding shops where it is already available for oxy-acetylene welding. Coal gas and propane are also often used.[2]

Propane is a hydrocarbon gas which is usually stored in steel cylinders at up to 150 lb. per square inch pressure. The volume of propane required in the oxygen-propane flame is less than that of acetylene required in the oxy-acetylene flame but the required volume of oxygen is much greater. The temperature is lower than that of the oxy-acetylene flame. This delays the starting of the cut, but, on the other hand, reduces the danger of overheating and consequent defects in the flame-cut edge. For this reason it is considered that a better quality of flame-cut edge can be obtained with propane than is possible with acetylene.

Coal gas, when used from the mains should have a calorific value of at least about 500 B.Th. U.

To maintain a certain minimum pressure, a small rotary compressor is sometimes installed.

A method which more than doubles the calorific value of coal gas, called " Ferrolene ", consists of injecting a certain amount of ether (about 30 per cent) into the coal gas after it has been compressed.

When using coal gas from the mains, a non-return valve has to be fitted in the gas supply line to prevent back-firing into the mains. Coal gas and hydrogen cannot be used for cutting cast iron, and cutting speeds obtained with these gases are lower than those obtained with the oxy-acetylene flame.

---

[1] E. Seymour Semper, " Oxygen Cutting," *Welding*, July 1946.

[2] E. Seymour Semper, " Oxygen Cutting," *Welding*, November 1947.

The oxygen and fuel-gas cylinders are the same as used in gas welding (see Fig. 2.1), but a special cutting blowpipe (Fig. 10.2) is used, which carries out two tasks. It provides the oxy-acetylene flame which heats the material up to combustion temperature, and it supplies the oxygen jet which is thrown on to the part to be cut. The mixed gases for the heating flame leave the blowpipe through an exit *a* and an annular opening surrounding a central nozzle *b* which supplies the cutting oxygen jet (Fig. 10.3). Nozzles in which the heating flame precedes the cutting oxygen jet (Fig. 10.4) are being used for cutting thin plates, but with such nozzles cutting is possible in only one direction (the

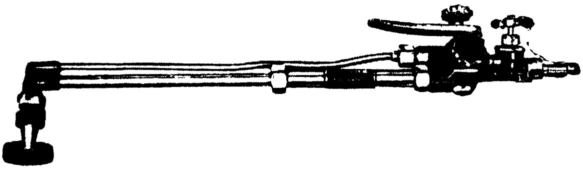


Fig. 10.2. Fiame-cutting Blowpipe (*B.O.C.*)

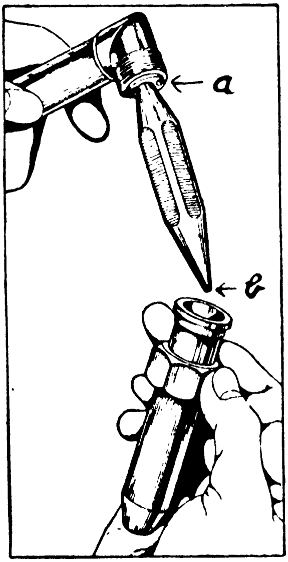


Fig. 10.3. (*B.O.C.*)

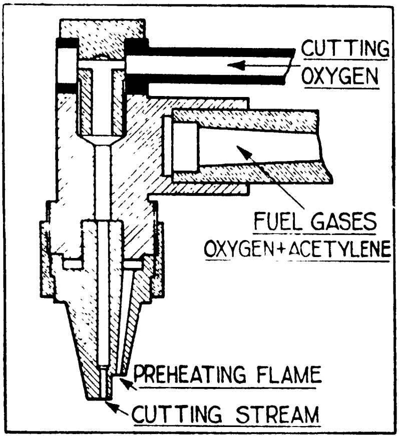


Fig. 10.4.
Flame-cutting Head (*B.O.C.*)

preheating flame must always be ahead of the oxygen jet in the direction of the cut), and profile cutting is difficult.

Valve handle (A, Fig. 10.5) serves for controlling the acetylene supply, handle (HO) for adjusting the flow of the heating, handle (CO) for adjusting that of the cutting oxygen. Heating and cutting oxygen are both taken from the same oxygen supply which is divided by the valves controlled by handles (HO) and (CO). After the gas supplies have been adjusted, the operator heats the material to be cut, with a neutral oxy-acetylene flame (D, Fig. 2.5), pressing down lever (L) in order to cut off the cutting oxygen supply. After the material has reached the required heat, the cutting oxygen is turned on by allowing lever (L) to go up, and the oxygen jet passes through the flame (E, Fig. 2.5).

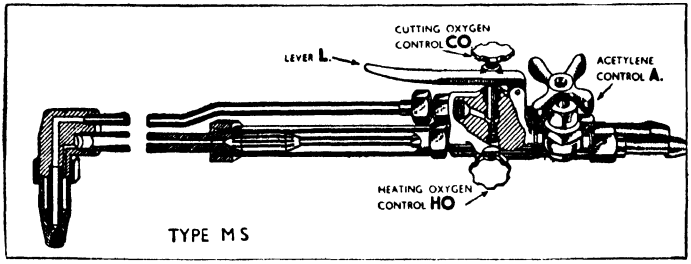


Fig. 10.5. Flame-cutting Blowpipe (*B.O.C.*)

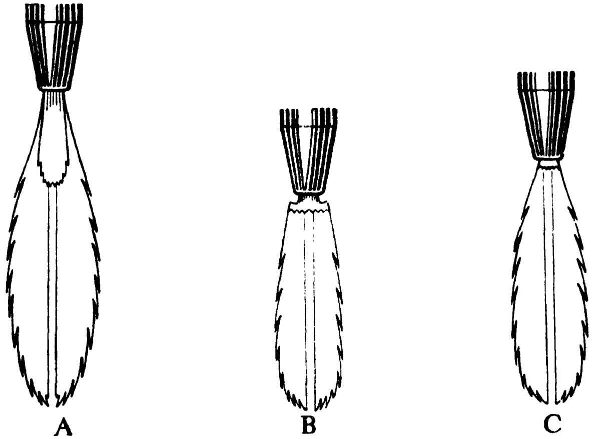


Fig. 10.6. (*B.O.C.*)

The oxy-acetylene flame should always be adjusted with the cutting oxygen supply open, as the latter might affect the condition of the heating flame. Fig. 10.6 A shows a flame with excess fuel gas, as used for cutting cast iron (see page 199), Fig. 10.6 B shows a flame with excess oxygen, and Fig. 10.6 C shows the flame set correctly for cutting steel.

The quality of the cut depends mainly on the following conditions which have to be chosen in accordance with the quality, condition, and size (thickness) of the material to be cut: the blowpipe nozzle size and the condition of the nozzle orifice, the adjustment of the heating flame, the correct position and distance of the nozzle from the material surface, and the speed of cutting. The influence of these factors on the appearance of the flame-cut edge can be seen from Fig. 10.7. Typical recommended settings for cutting steel can be seen from Table 32.

Oxy-Acetylene Cutting Data for Steel.[1]

TABLE 32

Mild steel plate thickness	Hand Cutting			Machine Cutting			
						Oxygen pressures	
	Nozzle size	Cutting speed	Oxygen pressure	Nozzle size	Cutting speed	Cutting	Heating
inches	inches	feet/hour	lb./sq. in.	inches	feet/hour	lb./sq. in.	lb./sq. in.
$\frac{1}{8}$ and $\frac{3}{16}$	—	——	—	$\frac{1}{32}$	160	40	15
$\frac{1}{4}$	$\frac{1}{16}$	100/125	20/25	$\frac{3}{64}$	75	15	20
$\frac{1}{2}$	$\frac{1}{32}$	50/60	30/35	$\frac{3}{64}$	65	30	20
$\frac{3}{4}$	$\frac{1}{16}$	70/90	30/35	$\frac{1}{16}$	60	35	20
1	$\frac{1}{16}$	60/80	35/40	$\frac{1}{16}$	50	37	20
$1\frac{1}{2}$	$\frac{1}{16}$	40/60	40/45	$\frac{1}{16}$	42	42	25
2	$\frac{1}{16}$	35/45	45/50	$\frac{1}{16}$	37	47	25
3	$\frac{5}{64}$	30/40	50/55	$\frac{5}{64}$	30	52	30
4	$\frac{5}{64}$	25/30	50/55	$\frac{5}{64}$	28	55	30
5	$\frac{1}{16}$	20/25	60/70	$\frac{5}{64}$	25	65	30
6	$\frac{5}{64}$	20/25	60/65	$\frac{3}{32}$	24	70	35

NOTE. Acetylene pressure at Regulator = 2–3 lb./sq. inch.

[1] The British Oxygen Co. Ltd.

Too large a heating flame results in fusion of the top surface of the plate to be cut, and—in addition—decarburization in case of a hydrogen flame or carburization in case of an acetylene flame. The effect becomes more pronounced if concentric nozzles are used (see Fig. 10.1), as the heating flame acts still on the portion which has

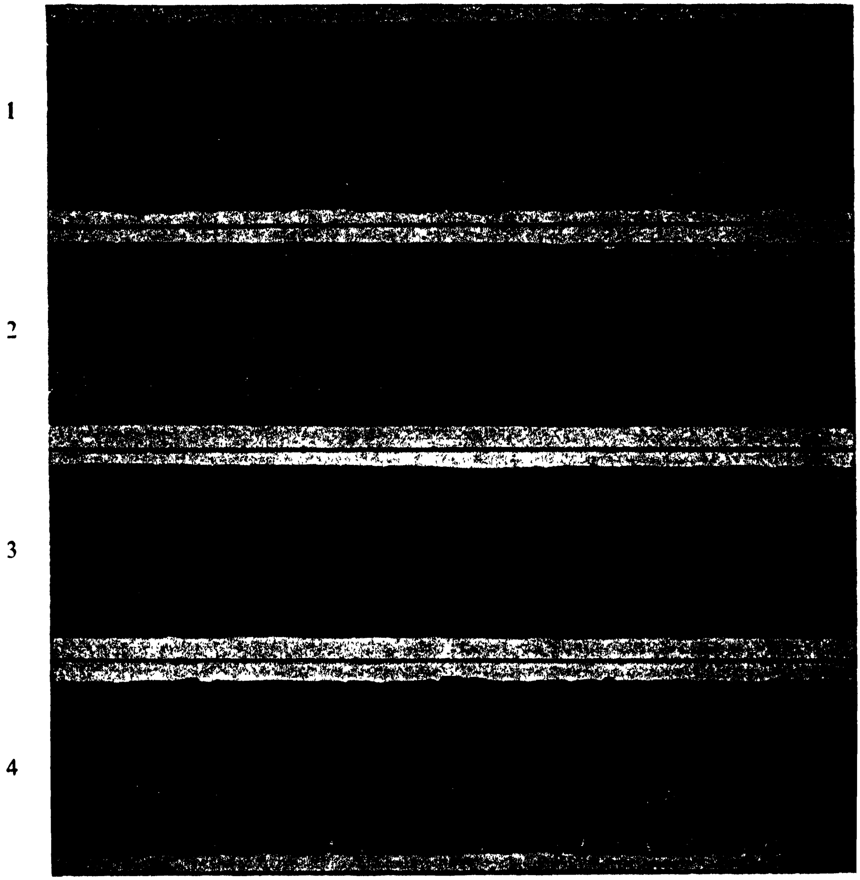


Fig. 10.7 (*a*). Influence of Various Factors on Appearance of Flame-cut Edge (*B.O.C.*)

1. Cutting speed too low. Under-cutting at bottom edge.
2. Cutting speed too high. Angle of drag exaggerated.
3. Normal cutting speed.
4. Dirty nozzle used. Rough surface, poor appearance.

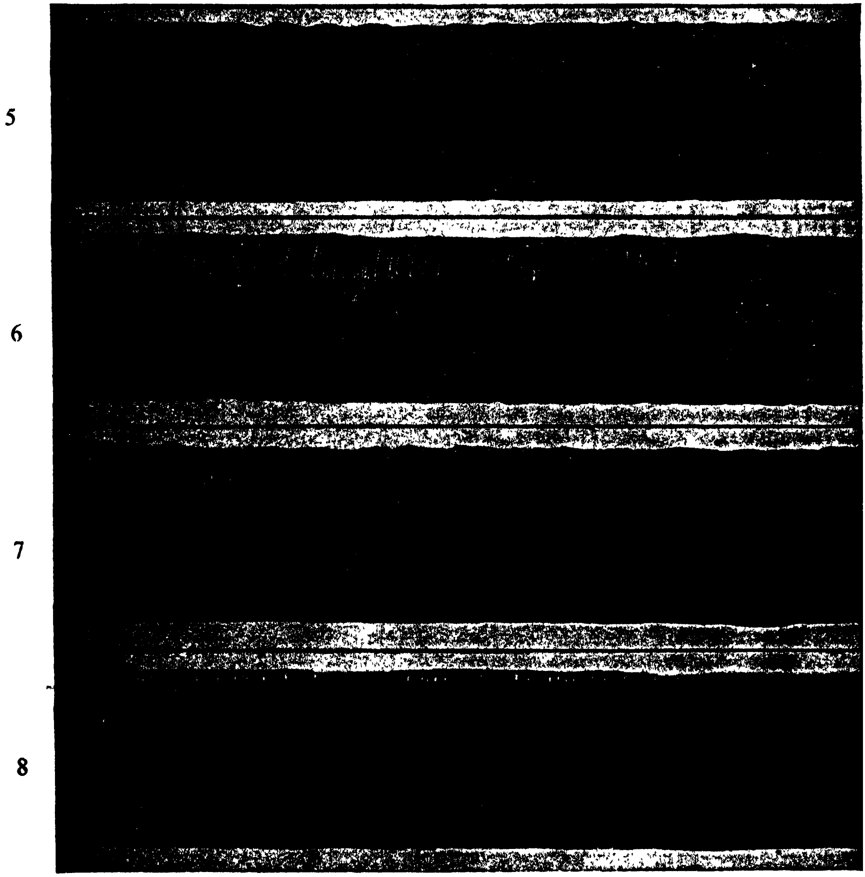


Fig. 10.7 (*b*). Influence of Various Factors on Appearance of Flame-cut Edge (*B.O.C.*)

5. Excess heating flame during cut. Fusion of top surface.
6. Excess cutting oxygen. Ripple effect on cut ; concave surface.
7. Nozzle too far from work. Fusion of top surface.
8. Nozzle too near work. Ripple effect at top ; concave cut.

already been cut, while preheating the portion which is still to be cut. For this reason nozzles of the type shown in Fig. 10.4 are preferred for cutting thinner plates, as they avoid the postheating effect. Special blowpipes using this type of nozzle have been developed for cutting very thin sheet steel.

Maintaining the correct distance between nozzle and plate can be facilitated by the use of rollers or guides on the blowpipe (see Fig. 10.2).

For cutting irregular sections, pressures and cutting speeds may have to be adjusted to suit the variation in thickness during the cutting operation. Cutting should also be started at a clear edge, and—in case of cutting out openings in a plate—a hole should be drilled, which is used as starting point of the cutting operation

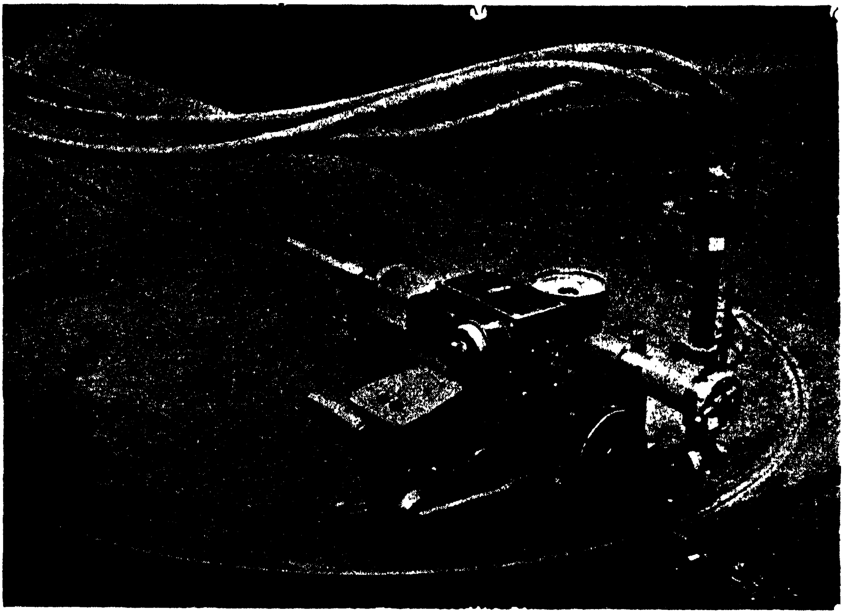


Fig. 10.8. Flame-Cutting Machine (*B.O.C.*)

For cutting round bars a notch should be chipped out at the surface to provide a start for the cutting operation.

The efficiency of the cutting operation and the quality of the cut can be greatly improved by guiding the blowpipe mechanically, instead of relying upon the—obviously varying—steadiness of the operator's hand. Portable blowpipe-carrying apparatus is often supported by the plate itself to be cut (Fig. 10.8) and guided either by a template in accordance with the desired profile to be produced (Fig. 10.9) or—in case of cutting circular shapes—by a radius bar (see Fig. 10.8).

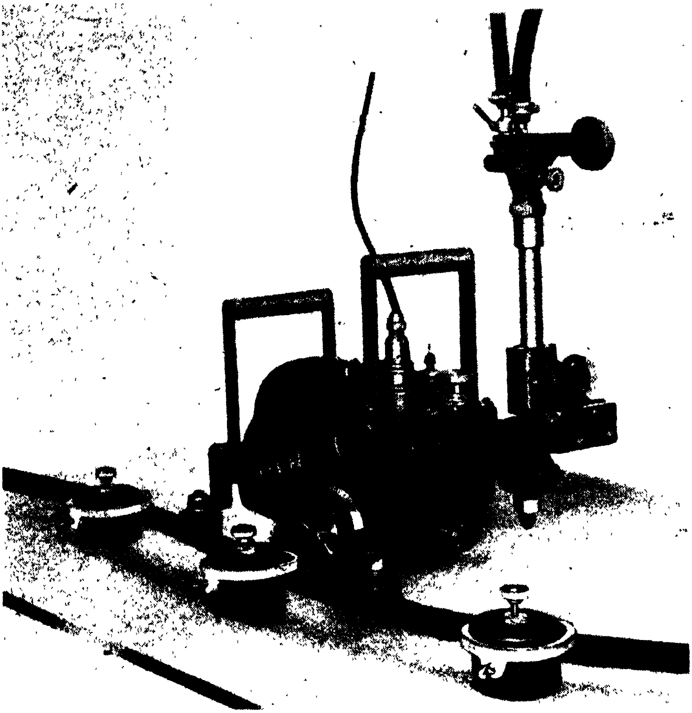


Fig. 10.9. Portable Flame-Cutting Machine, fitted with Crabbing Rollers running against a Template Strip which is held in position on the plate by small Permanent Magnets (*Hancock*)

Portable cutting machines may also be supported and guided by a rail arrangement (see Fig. 10.13). A small electric motor and a speed-change device drive the wheels which give the machine the required cutting speed.

For cutting plate components covering a large area, profiling machines of the type shown in Fig. 10.10 have been developed. Here the cutter slide carries at the rear end the motor-driven tracer roller, and at the front end the cutting blowpipe, templates being fastened to the table in the rear of the picture, and the cutter carrier following their profile through its two-dimensional sliding arrangement.

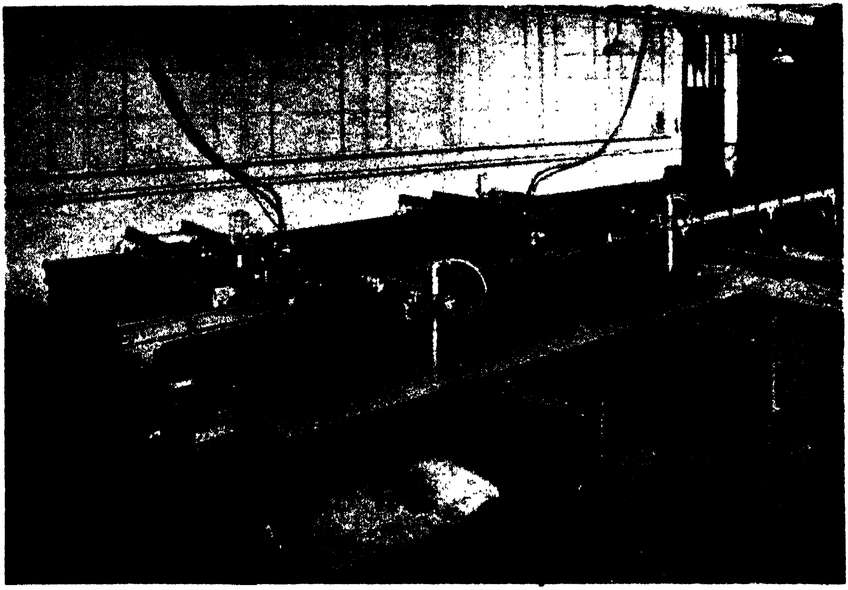


Fig. 10.10. Longitudinal Profiling Machine having a cutting area of 50 ft. x 7 ft. fitted with two burners suitable for profiling loco frames (*Hancock*)

For cutting smaller components pantograph machines (Fig. 10.11) are used. In these machines a template guides the pantograph arm which carries the blowpipe. By connecting several pantograph arms in parallel, more than one component can be reproduced from one template.

Magnetic rollers, or twin rollers are used for holding the guiding device in contact with the guiding (template) strip, and feeler fingers or tracers are used for hand guiding the pantograph arm along the outlines of a template or a drawing.

When flame-cutting large pipes to length, difficulties might be encountered if the pipes are slightly irregular in shape, and the distance between nozzle and material surface varies accordingly during the cutting operation.

The "floating head" device (Fig. 10.12) overcomes this difficulty. The whole apparatus is fastened to the pipe to be cut, and a tracer roller connected to the nozzle head and lying just behind it, makes the latter follow any irregularities in the pipe surface.

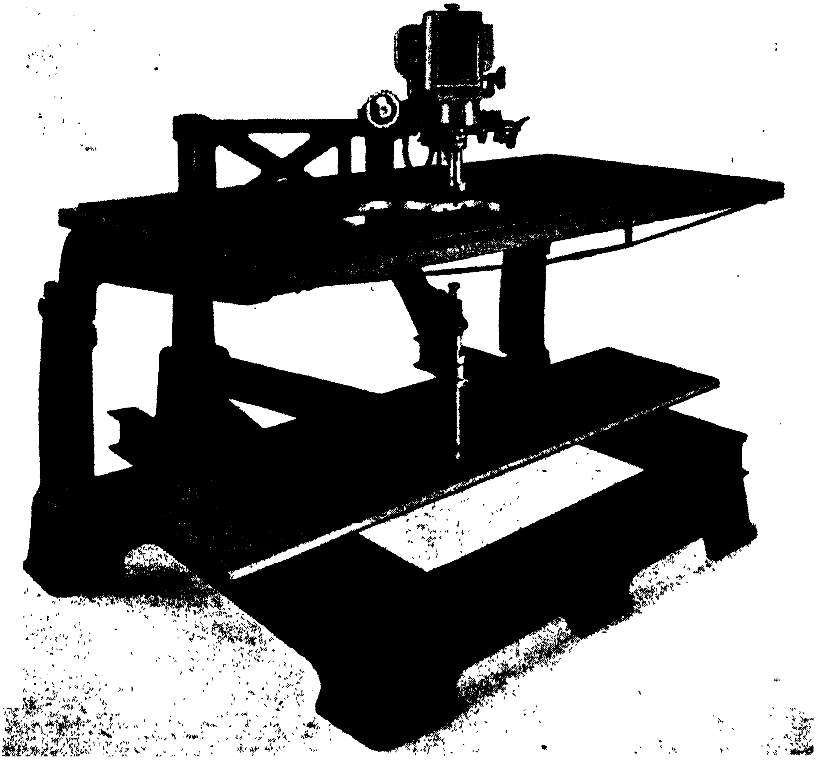


Fig. 10.11. Pantograph Flame-Cutting Machine, with U-shaped arm carrying driving tracer gear (top) and cutting blowpipe (bottom) and using strip aluminium Template (*Hancock*)

Flame-cutting machine blowpipes are often equipped with two separate oxygen supplies. This makes independent adjustment of heating and cutting oxygen possible, and is particularly important for cutting thick plates, when the required pressure of the heating oxygen is not necessarily equal to that of the cutting oxygen.

Bevel edge plate preparations for welding (see page 43) can be carried out simultaneously with the actual cutting operation by using

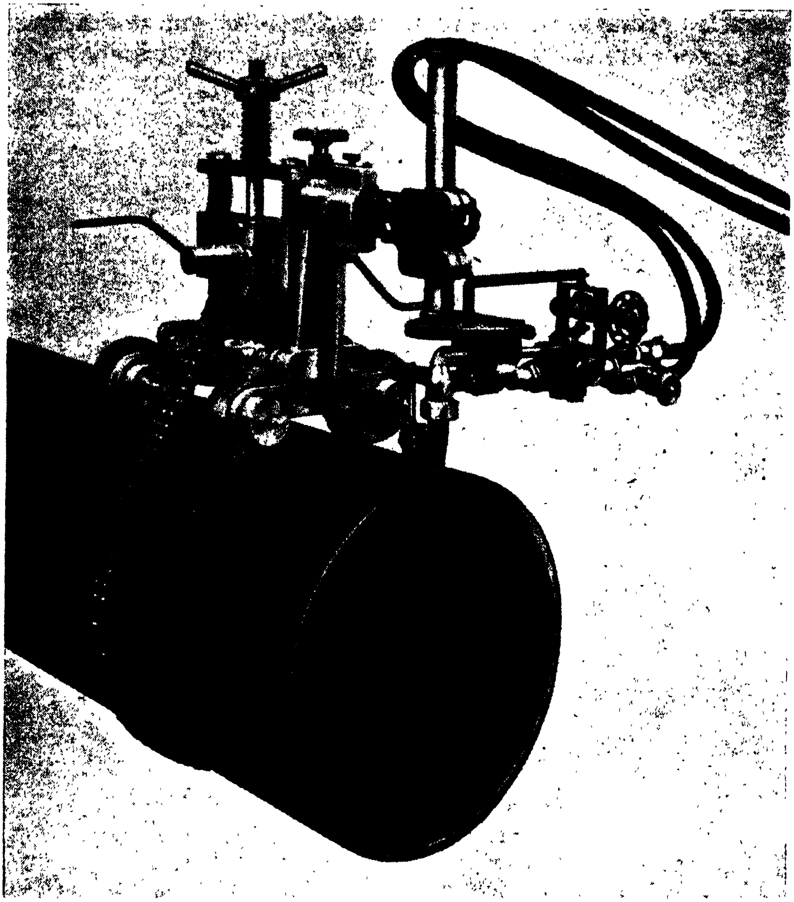


Fig. 10.12. Pipe-Cutting Machine fitted with floating head burner to maintain nozzle at a constant height above the surface (*Hancock*)

several blowpipes which are arranged in series in one cutting head (Fig. 10.13). The procedure applied for the production of various bevel edge preparations can be seen from Fig. 10.14. Flame-cutting production output can be increased, and thin sheets can be successfully flame cut by using the stack-cutting method, i.e. clamping several plates tightly together and cutting them simultaneously. It is important, when stack cutting, to prevent air gaps from developing between the plates through distortion and warping of the sheets,

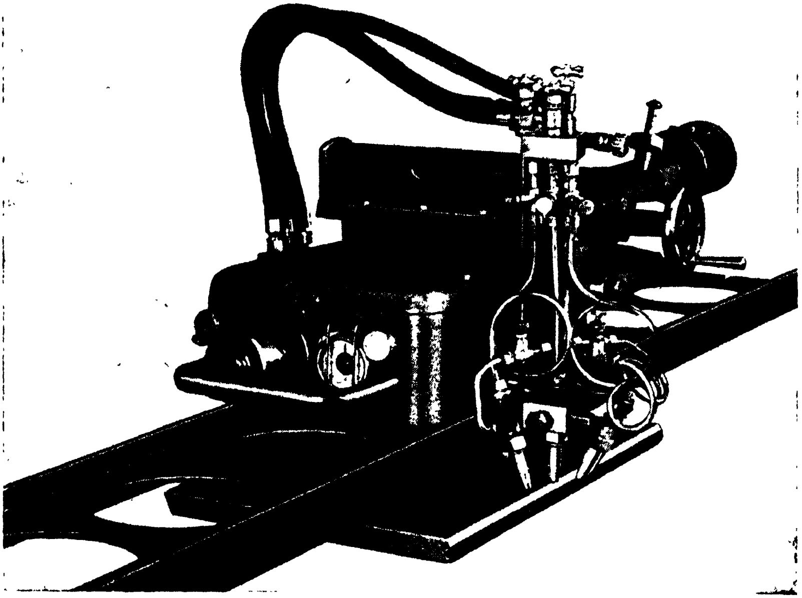


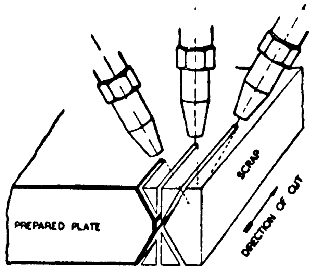
Fig. 10.13. Flame Cutting Machine equipped with three nozzles for cutting bevel edge preparation for welding (*B.O.C.*)

because such gaps allow the gas stream to wander between the plates and cause inaccuracies and bad quality of the flame-cut edges. For the same reason, the removal of loose mill scale and rust which also stop heat dissipation and cause overheating of the top layers is more essential still in stack cutting than in the case of cutting single plates.

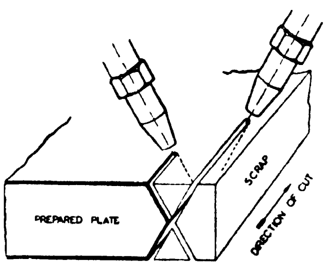
The accuracy obtained in machine flame cutting steel plates depends upon the factors mentioned in connection with the efficiency of the flame-cutting process itself and—obviously—upon the accuracy and rigidity of the flame-cutting machine and the blowpipe parts which determine the shape and direction of the cutting jet. The width of the flame cut which has to be taken into consideration when designing templates varies between about $\frac{1}{32}''$ for plates below $\frac{3}{8}''$ thickness and $\frac{7}{32}''$ for plates of 12″ thickness.[1] Accuracies across the cut of 0·003″ on 1″-thick plate and 0·0312″ on 6″ plate have been obtained commercially with machine flame cutting,[1] when all settings and cutting conditions were carefully watched and maintained.

---

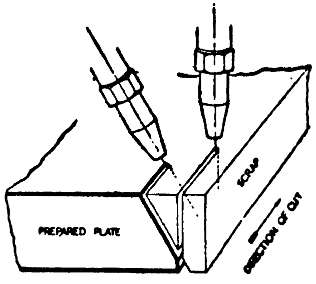
[1] E. Seymour Semper, "Oxygen Cutting," *Welding*, September 1946.



DOUBLE BEVEL AND NOSE.



DOUBLE BEVEL.



SINGLE BEVEL AND NOSE.

Fig. 10.14. (*B.O.C.*)

The heating and subsequent cooling due to the quenching effect of the plate, has a hardening effect on the material at the flame-cut edge. Due to the relatively high cutting speed, however, the heat input into the plate material is not large enough to affect the material at any considerable distance from the flame-cut edge. Experiments have shown that the depth of the heat-affected zone in mild steel is not exceeding $\frac{1}{8}''$ in many cases being far less than that amount. It has also been established[2] that the reduction in fatigue strength sometimes encountered in flame-cut components is due to the fine serrations of the flame-cut edge and not to any metallurgical changes in the material. If the component in question is likely to be subjected to fatigue loads in service, these serrations have to be ground away, unless they are melted away in a subsequent fusion welding operation. The more accurate and smooth the work of the flame-cutting machine, however, the less pronounced will be the reduction in fatigue strength of the component.

The thermal effect of the flame-cutting process depends also upon the composition of the material to be cut, and—similar to fusion welding processes—flame cutting of high carbon steels and high tensile alloy steels requires preheating (300°–400°C.) in order to prevent hardening and surface cracking.

---

[1] G. M. Boyd, " Flame Cutting in the Shipyard," *Transactions of the Institute of Welding*, July 1944.

[2] O. Graf, " Uber Dauerzugversuche und Dauerbiegeversuche an Stahlstäben mit Brenngeschnittenen Flächen " (Fatigue Tensile and Bending Tests on Steel Bars with Flame Cut Edges), *Forschungsarbeiten auf dem Gebiete des Schweissens und Schneidens* (Machold, Halle, 1936).

Silicon and graphitic carbon contained in *cast-iron* are not only difficult to oxidize but also form oxides with a melting point which is higher than that of the cast iron itself. Cast iron cannot, therefore, be flame cut in a way that produces a clean cut surface as in the case of steel.

For demolition and similar purposes, however, and also for chamfering edges to prepare broken castings for welding, a process can be applied in which the metal is melted with a blowpipe, and the molten metal and the slag then blown away by a jet of high pressure oxygen. The gas passages in the blowpipe, both for oxygen and acetylene, are larger and the gas consumption is higher than in the case of cutting steel. An excess acetylene heating flame (see Fig. 10.6 A) is recommended, as the resulting slag becomes more easily removable by the oxygen jet.

TABLE 33

Approximate Data for Cast Iron Cutting[1]

Metal thickness (inch)	Nozzle size (inch)	Distance from work (inch)	Oxygen pressure (lb./sq. inch)	Length of white cone (inch)	Approx. speed of cutting (ft./hr.)
Up to 1½	3/64	3/8	110	2	12
1½– 3	1/16	1/2	120	3	9
3 – 5	3/32	1/2	130	3½	7
5 – 8	3/32	5/8	140	4	5
8 –11	7/64	5/8	150	4	3
11–14	1/8	3/4	150	4	2
14–16	1/8	3/4	160	4	1½

[1] British Oxygen Co., Ltd.

Approximate settings for cutting cast iron are shown in Table 33. The cutting technique consists in heating an area of about ½″ to ¾″ diameter (Fig. 10.15 A) and, after opening the oxygen jet valve, moving the blowpipe along the line of the intended cut with a swinging motion covering a width of about ½″ (Fig. 10.15 B). An iron filler rod fed on to the surface to be cut assists oxidization and facilitates starting the cutting operation.

The cutting of *stainless steels*[1] is particularly difficult, because these steels are made to resist oxidization, and the melting point of chromium and nickel oxides is higher than that of the stainless steel itself.

A technique similar to that of cutting cast iron has been employed for cutting off risers from stainless steel castings and for similar applications, the use of a steel filler rod for starting the cut serving for reducing the proportion of chromium oxide and providing additional heat from the reaction between mild steel and oxygen.[1] Another method consists of placing mild steel sheets on the surfaces of the stainless steel plate to be cut, or—in case of stack cutting—as jackets or interlaminations in the stack of stainless steel sheets, thus providing layers of material better to cut for initiating the cutting process. The latest development is the use of a flux which is drawn in by the high pressure oxygen, and which is claimed to make possible a flame-cutting operation similar to that for mild steel.

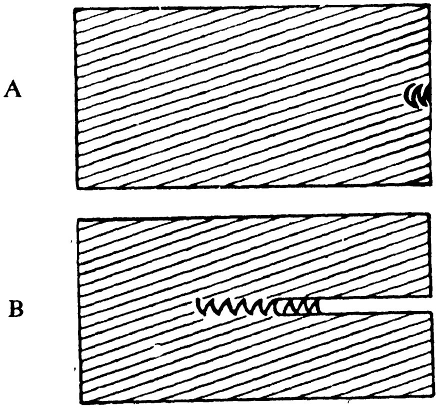


Fig. 10.15. (*B.O.C.*)

When cutting 18/8 stainless steel the danger of "weld decay" (see page 112) exists, similar to the condition obtained with fusion welding, and similar precautions as mentioned previously (see page 112) have to be taken.

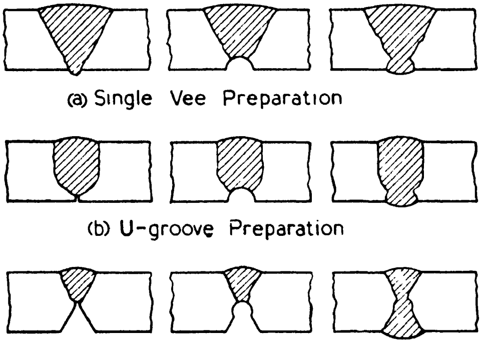
Another recent development is the oxy-arc cutting process,[2] in which the heat is provided by an electric arc struck between an electrode and the material to be cut. Due to the intense heat of the electric arc, preheating times are much shorter and cutting speeds higher than in the case of oxy-acetylene cutting. The process has proved particularly advantageous for cutting cast iron and stainless steel.

---

[1] See E. Seymour Semper, "Oxygen Cutting," *Welding*, July 1947.

[2] See R. N. Thompson, "Oxy-arc Cutting," *Welding*, August 1947.

The electrode is held in a special torch and consists of a coated steel tube, through whose bore passes the cutting oxygen. The oxygen stream is controlled by a trigger-operated valve in the torch. During the cutting operation the electrode rests on the plate to be cut, thus keeping automatically the correct distance between oxygen outlet and plate surface.



(a) Single Vee Preparation

(b) U-groove Preparation

c) Double Vee Preparation.

The use of Flame Gouging for removing the underside of conventional butt weld designs in preparation for rewelding from reverse side

Fig. 10.16. Application of Flame Gouging (*B.O.C.*)

Flame Gouging. Flame gouging is a special application of the flame-cutting process, the main difference being found in the fact that the cutting action does not penetrate the full thickness of the component material, and that it can be limited to any required depth. Originally developed for removing the underside of butt welds prior to welding from that side (Fig. 10.16) or for removing defective parts of welds prior to rewelding, the process is now frequently employed for plate edge preparations for J- and U-butt welds (Fig. 10.17). The cutting speeds obtainable make this latter application economically far superior to the otherwise necessary machining operations.

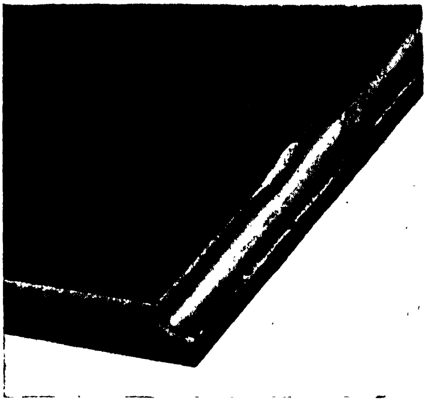


Fig. 10.17.
Flame-gouged plate edge (*B.O.C.*)

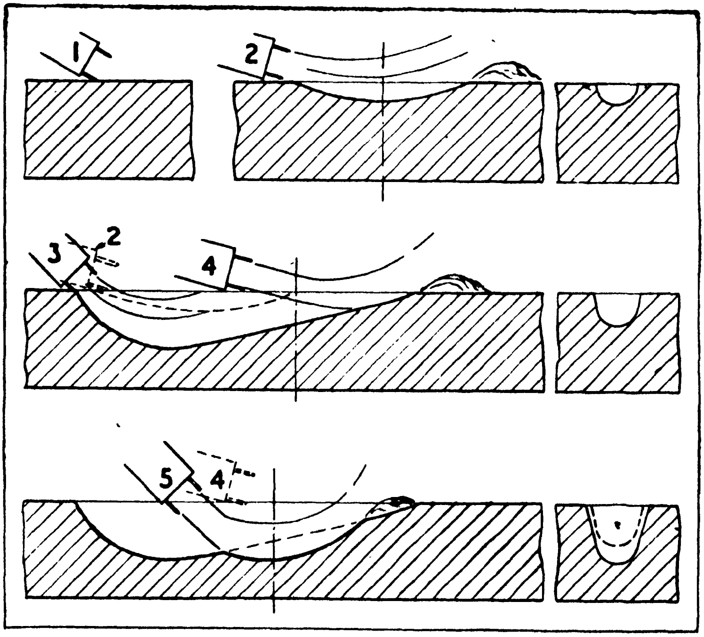


Fig. 10.18. Flame-Gouging Technique (*B.O.C.*)

The gouging technique can be seen from Figs. 10.18 and 10.19. Special nozzles (Fig. 10.20) provide the correct heating flame distribution and the correct size and direction of the oxygen jet. The slag cannot fall or be blown down, as the bottom of the flame-cut groove is closed, but it can be easily removed by wire-brushing or scraping.

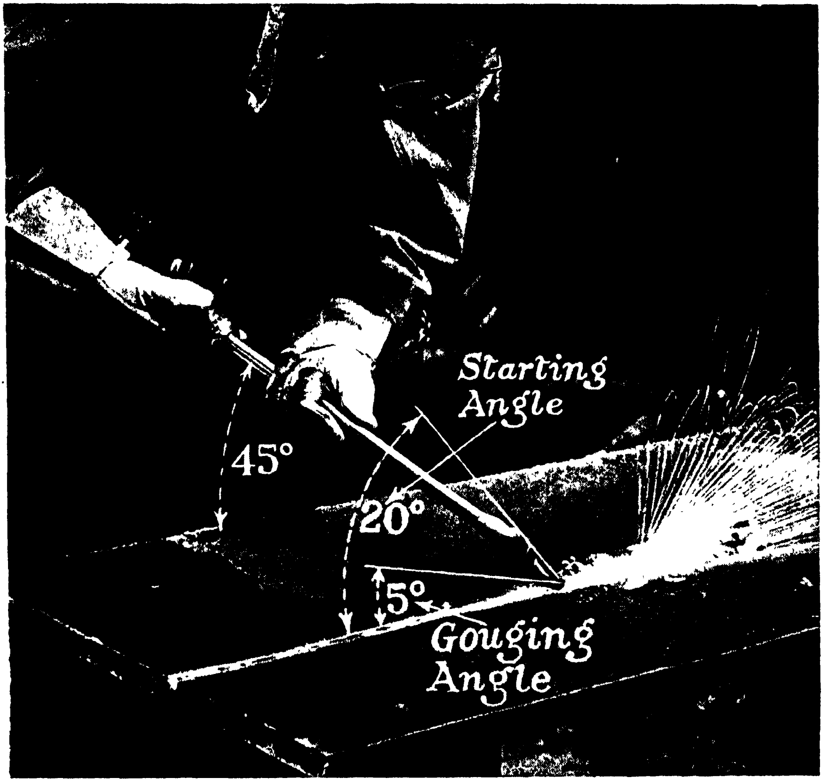


Fig. 10.19. Flame-Gouging Technique (*B.O.C.*)

Thermal effects or small serrations are of practically no importance in the case of flame gouging, as the gouged area is afterwards covered with weld metal and the fusion of the gouged surface has an annealing effect and eliminates the serrations. Typical settings and gouging speeds are shown in Table 34.

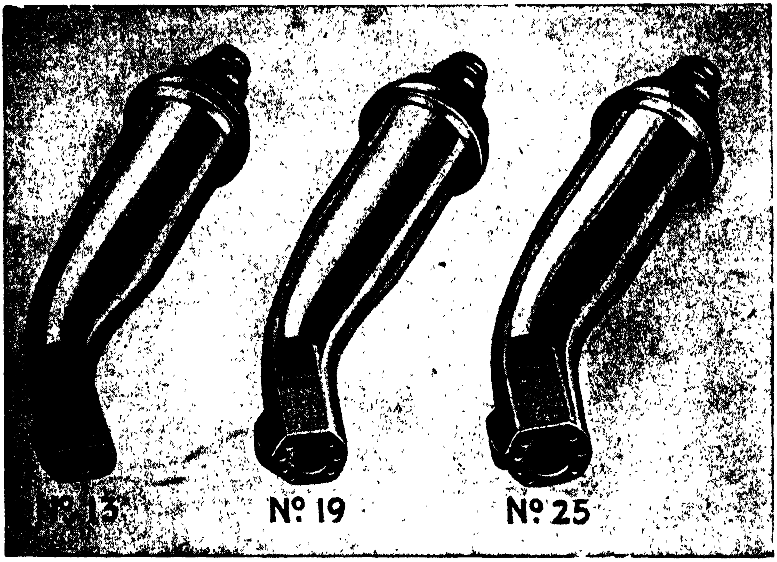


Fig. 10.20. Flame-Gouging Nozzles (*B.O.C.*)

TABLE 34

Recommended Operating Data for Manual Oxy-Acetylene Flame Gouging

Nozzle number*	Approximate dimensions of Groove		Regulator pressure in lb./sq. in.		Approximate Gouging speed in ft. per min.
	Width, inches	Depth, inches	Acetylene	Cutting oxygen	
13	$\frac{5}{16}$	$\frac{1}{8}$–$\frac{1}{4}$	2–10	45–60	1·0–1·8
19	$\frac{7}{16}$	$\frac{1}{4}$–$\frac{3}{8}$	2–10	60–80	1·9–2·2
25	$\frac{1}{2}$	$\frac{3}{8}$–$\frac{7}{16}$	2–10	75–100	2·2–2·8

(British Oxygen Co., Ltd.)

* The nozzle size numbers represent the diameter of the cutting oxygen orifice in hundredths of an inch, for example nozzle number 13 has a cutting oxygen orifice of 0.13″ diameter.

CHAPTER XI

WELDING MANIPULATORS AND FIXTURES[1]

A FUNDAMENTAL condition for the efficiency of welding as a production method is ease in handling fabricated structures in order to obtain correct positioning and good accessibility of the welds. In electric-arc welding, for example, the "downhand" welding position (see page 46) is the most favourable one, due to the possibilities of using large size electrodes, the reduction in fatigue of the operator, and the higher welding speeds obtainable.

When using cranes for positioning large welded assemblies, such as to make downhand welding possible, the cost and difficulties involved may overshadow the advantages gained. Welding positioners, also called manipulators, have, therefore, been developed, which allow even large size welded fabrications to be handled by the welder, to suit his requirements.

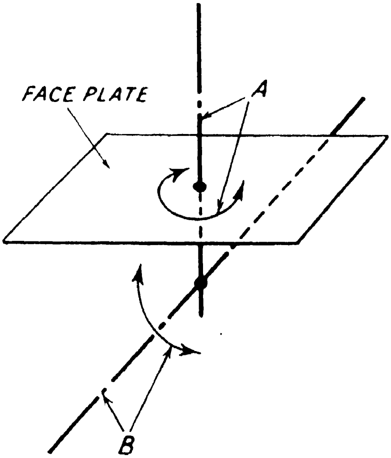


Fig. 11.1

For welding circular vessels, roller beds (see Figs. 1.8 and 2.34) are often employed, but for more general application universally movable face plates are used, on to which the fabricated structures are clamped in the pre-assembled, tack-welded stage. The face plates can be rotated round a central axis (A, Fig. 11.1) and round an axis

---

[1] See *Memorandum on Jigs and Manipulators for Fusion Welding,* issued by the Advisory Service on Welding, Ministry of Supply.

(B) at 90° to (A), thus allowing universal movements in three dimensions. While such manipulators may be operated by hand when dealing with fabricated structures of low weight (up to 15 cwt.), power operation is required for manipulating heavier structures.

Fig. 11.2 shows a manipulator capable of handling fabricated structures up to 2 tons in weight. Face plate *a* can be rotated round axis (A) by means of a motor drive acting on bevel-gear crown wheel *b*, and the whole arrangement can be tilted round horizontal axis (B) by a motor drive acting on spur wheel segment *c*. The trunnions carrying the moving portion on axis (B) are supported in the rigid bearing carrying stands *d* whose shape allows a tilting movement of face plate *a*, of 135° from the horizontal face plate position shown in the picture. The motors are operated through push button controls *e*, and automatic electromagnetic brakes are provided, which stop the movement and hold the table in any desired position immediately the motor drive is switched off.

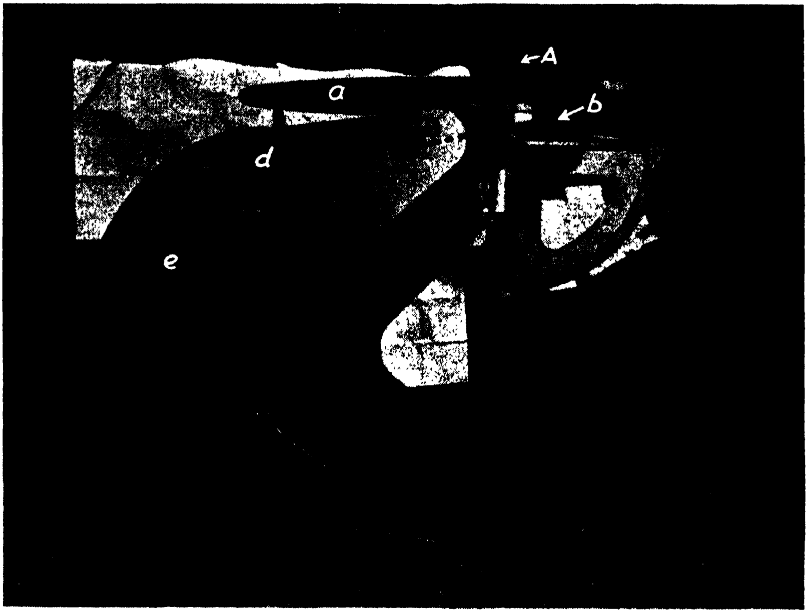


Fig. 11.2. Two-Ton Manipulator (*Metropolitan-Vickers*)

The loading capacity of a manipulator does not depend only upon the dead weight of the structures to be handled. The position of the centre of gravity of the latter, in relation to the two axes of rotation, determines the moments exerted on the manipulator structure and on the driving gear (see Figs. 11.3 and 11.4).

The height h of the centre of gravity (G) above the table surface and the distance e (eccentricity) from the rotation axis (A) determine the leverage l_1 with which the weight (W) acts in relation to the tilting axis, and with it the moment (M_1) exerted on the tilting drive (Fig. 11.3). This moment grows with increasing tilting angle (axis of rotation A′, position of centre of gravity G′), the maximum being reached when the table is tilted 90° to the horizontal. In a similar way the moment exerted on the table rotation drive (Fig. 11.4) depends upon the distance e of the centre of gravity (G) from rotation axis (A), the maximum occurring when the table is tilted 90° and the line G–A is horizontal ($\alpha = 90°$ and $\beta = 90°$).

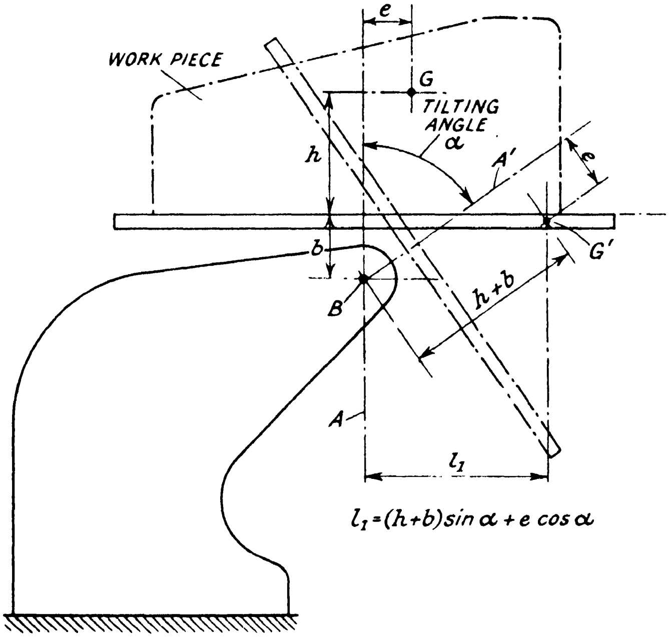


Fig. 11.3

Fig. 11.4 shows the conditions for a general case of α and β, and the tilting and rotating moments exerted by the weight W on the respective drives are indicated neglecting friction.

From the foregoing it will be appreciated that the loading capacity of a manipulator has to be determined for specified positions of the centre of gravity of the components to be carried.

This applies particularly to the height h above the table surface (dimension b, Fig 11.3, being a constant), as within limits the

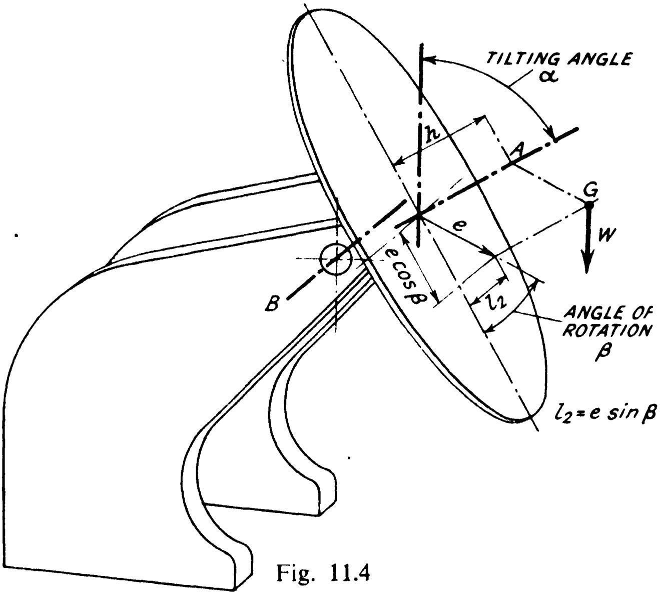


Fig. 11.4

Tilting Moment: $M_1 = W \times [(h+b)\sin\alpha + e\cos\beta\cos\alpha]$
For $\alpha = 90°$ and $\beta = 0°$: $M_{1\,\max} = W(h \times b)$
Rotating Moment: $M_2 = W\sin\alpha \times e\sin\beta$
For $\alpha = 90°$ and $\beta = 90°$: $M_{2\,\max} = W \times e$
(see also Fig. 11.3).

eccentricity *e* can be arranged by suitably positioning the component on the table.

Capacity specifications for manipulators can be shown in graphical form (see Fig. 11.7) or in form of a table (Table 35).

TABLE 35
Welding Manipulators

Operation	Loading capacity	Maximum permissible distance of centre of gravity of work from the table, for weights given in second column
manual	7 cwt.	7 inches
,,	15 cwt.	8 inches
motor	2 ton	9 inches
,,	6 ton	18 inches

(Metropolitan-Vickers Electrical Co., Ltd.)

From the foregoing it will be seen that the relative position of axes (A) and (B), as well as the distance (*b*, Fig. 11.3) of the table surface from axis (B) influence the capacity of a manipulator and the driving power required to operate it.

Most favourable relations between the above factors have been worked out and applied in the design of the manipulator (Fig. 11.5)[1], which is patented. Distance *b* between table surface and axis (B) has been reduced to a minimum, and the position of axes (A) and (B) in relation to each other (Fig. 11.6) has been arranged so that minimum tilting and rotating moments result. The weight of driving motors and gears are used to assist balance weight (C) in counter-balancing

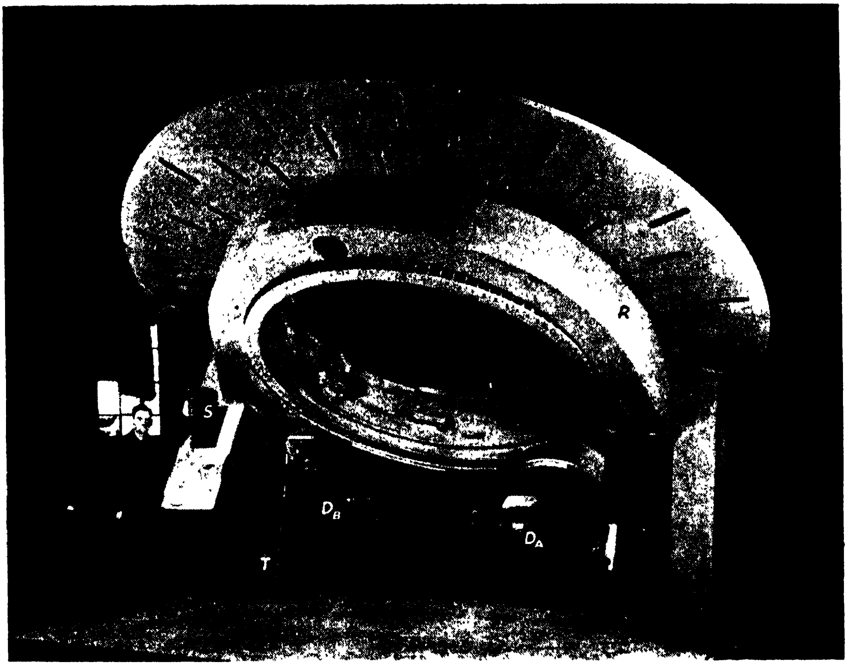


Fig. 11.5. Ten-Ton Manipulator (*Cooke and Ferguson*)

---

[1] Cooke and Ferguson Ltd., Manchester. See also R. Drucker, "Manipulators for Arc Welding, with Special Reference to a New Design of a Heavy All-purpose Face Plate Type of 10 tons Rated Capacity," Sir William Larke Prize Paper, *Institute of Welding*, 1944.

the weight of the component. For this purpose the tilting table support (R) is moving together with motors and gears during the tilting operation, the whole arrangement climbing along worm-wheel segment (S)

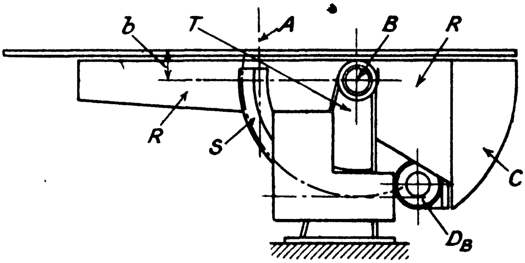


Fig. 11.6

on the left-hand trunnion support (T). The graph (Fig. 11.7) shows the load capacity of the manipulator for various positions of the centre of gravity of the work piece, and it will be seen that for the case of $h=6$ feet and $e=4$ feet (see Fig. 11.3) a welded structure of 10 tons weight can be handled, the capacity being increased if the centre of gravity of the work piece is in a more favourable position, i.e. for smaller values of h and e. The power required for operating this manipulator is 50 h.p. for the revolving drive (D_A) and 30 h.p. for the tilting drive (D_B) (Fig. 11.5). The high power requirements are due partly to the great values of h and e on which the designer based

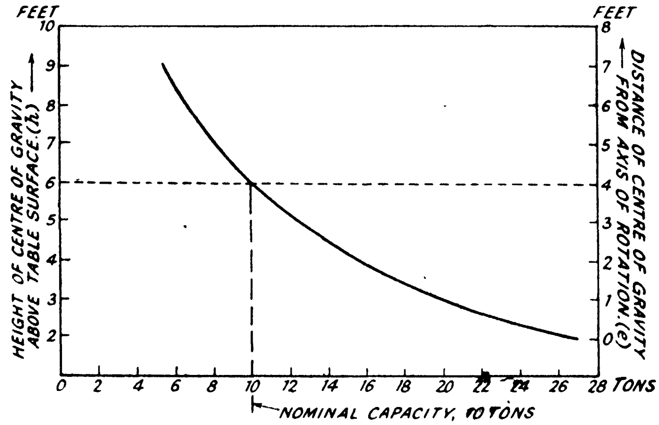


Fig. 11.7

the nominal capacity, partly to the intentional low efficiency of the worm-wheel drives, which are needed to make the driving gears irreversible and self-locking. Push button (dead man) controls are provided, and electro-magnetic brakes on the motor shafts ensure immediate stopping of the movements as soon as the push buttons are released.

Pits are usually provided in the installation of manipulators, in order to enable large protruding pieces being swung without difficulties.

When clamping heavy components to a manipulator care should be taken that expansion and loosening of the clamping bolts due to the welding heat does not cause serious damage. Under such conditions bolts which are intended to be in tension only (Fig. 11.8 a) may be stressed in shear (Fig. 11.8 b) by the weight of the sliding work piece, and if they give, the latter may slide off the manipulator.

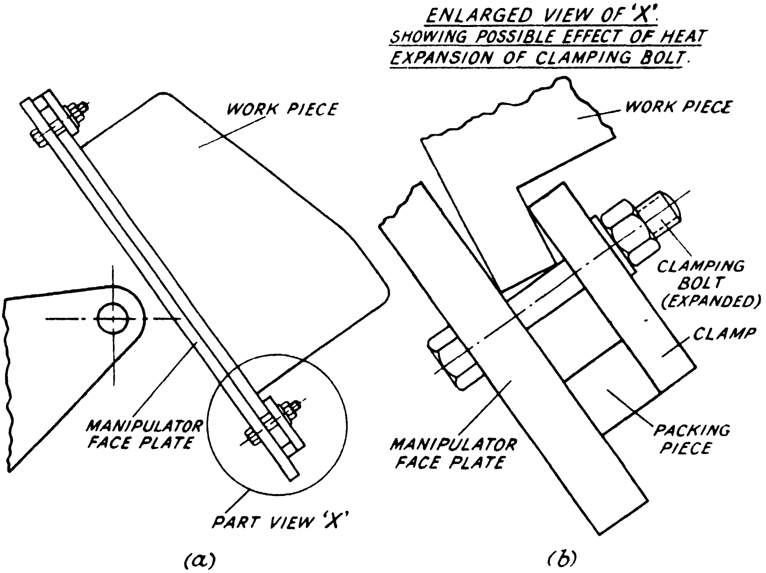


Fig. 11.8

To prevent this danger it is suggested to use separate stops against shifting all round the work piece (see Fig. 11.9). These stops may even be welded to the face plate, if it is feared that they, too, may be affected by the welding heat, a case which can, however, be considered unlikely.

Fig. 11.9[1] shows the arrangement of stops and clamps in a typical case of a fabricated structure being welded on a manipulator.

Special purpose *welding assembly fixtures* have proved useful for the sub-assembly or final assembly of welded structures, particularly if production in quantities is required.

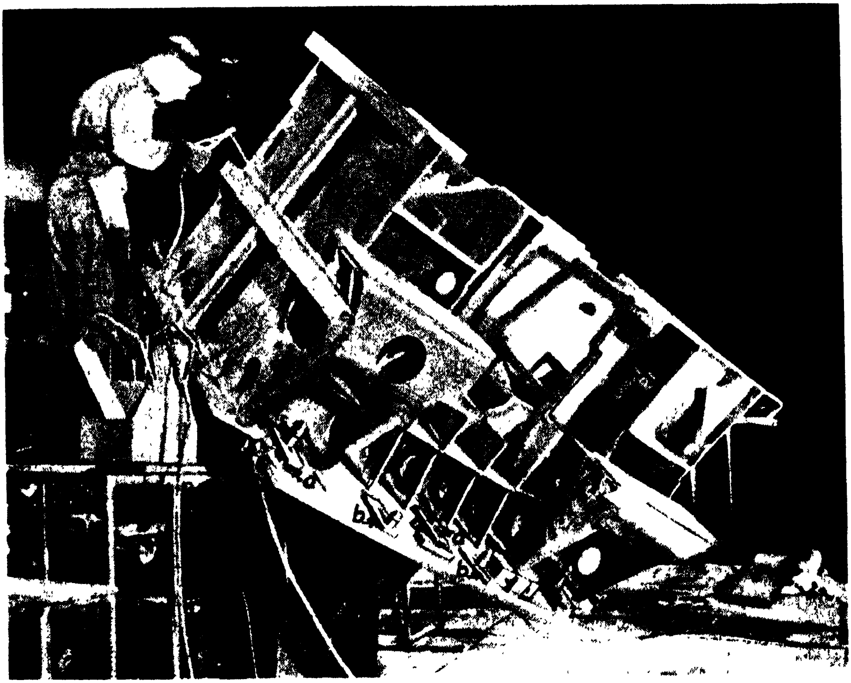


Fig. 11.9. Welding Manipulator
a, *a*, clamps. *b*, *b*, stops to prevent sliding

They have to locate the detail components and clamp them securely in position while the welding operations are in progress. At the same time they must allow free access to the welded joints. Fixtures are also used for tack welding only the detail components in position, after which operation the structure may be taken out and the welding be completed on a manipulator. In addition to holding the detail components in position the clamping is often used to prevent distortion during manufacture. This may, however, cause residual stresses in the structure (see page 233).

[1] Reduction gear case being welded at the works of Cooke and Ferguson Ltd., Manchester.

Welding fixtures become the more complicated the greater the number of detail components of the complete work piece. In the design of such complicated fixtures particular care must be taken to ensure that it is possible to withdraw the welded structure after completion. Once the work piece is welded it cannot be taken to pieces any more, and it has happened that during the try-out of a new welding fixture, parts had to be cut away, in order to take the finished product out of the fixture. There is also a possibility that distortion

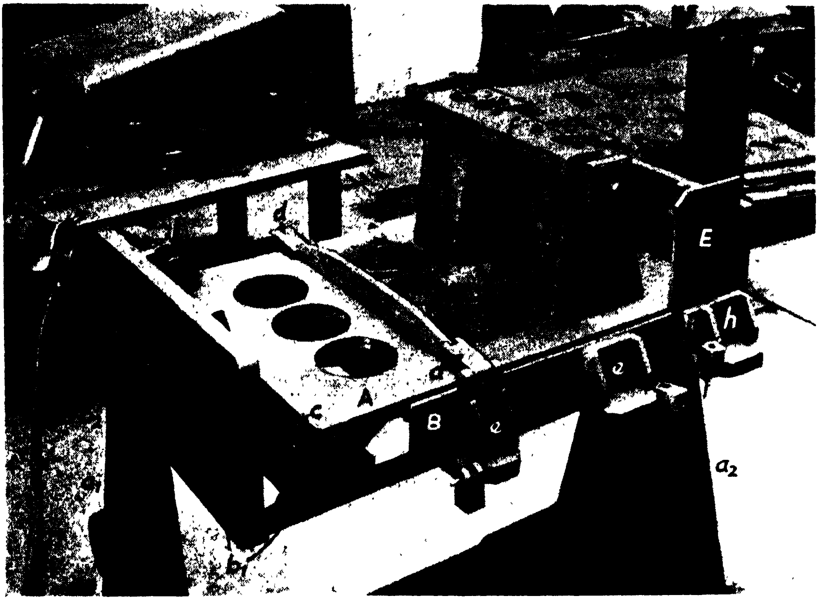


Fig. 11.10. Fixture for Welding Circuit Breaker Top Plate
(*Cooke and Ferguson*)

1. *Detail Components to be assembled*:
   A—Main Plate. *B*—Side Stiffener. *C*—Transverse Stiffener. *D*—Lever Bearing Housings (sub-assembled prior to final assembly in this fixture). *E*—Guide Plate.

2. *Fixture Parts*:
   a_1, a_2—Stands. b_1—Fixture Frame. b_2—Trunnion for swinging fixture frame round for positioning. *c*—Locating Pegs for Plate *A*. *d*—Locating Pegs for Stiffener *C*. *e*—Locating and Clamping Brackets for Stiffener *B*. *f*—Locating and Clamping Bracket for Housing *D*. *g*—Clamps for Plate *A*. *h*—Locating and Clamping Bracket for Guide Plate *E*.

during welding makes withdrawal of the finished structure difficult, and this point should also be kept in mind by the fixture designer.

The rules applicable to general jig-and-fixture design apply also to the design of welding fixtures. These must be accurate enough for the job; allow for the inaccuracies which must be reasonably expected from the components; and should be foolproof.

In addition to these points, fixtures for arc welding should be designed so that machined parts such as locating blocks and clamping screws, are protected from weld spatter.

A typical arc welding fixture is shown in Fig. 11.10.

In the design of fixtures for resistance welding, particularly spot and projection welding, various additional points have to be considered.[1] The question of current-carrying and insulating parts of the fixture is of particular importance. Current-carrying parts which transmit the welding current from a platen or an electrode to a detail component have to be made of high duty copper alloy. This will ensure low current losses and will reduce wear in the fixture. On the other hand, care must be taken to prevent current by-passing the components to be welded by travelling directly through the fixture, and good insulation between the parts carrying different detail components must be provided, if a one-piece fixture holds several parts (see Fig. 11.12).

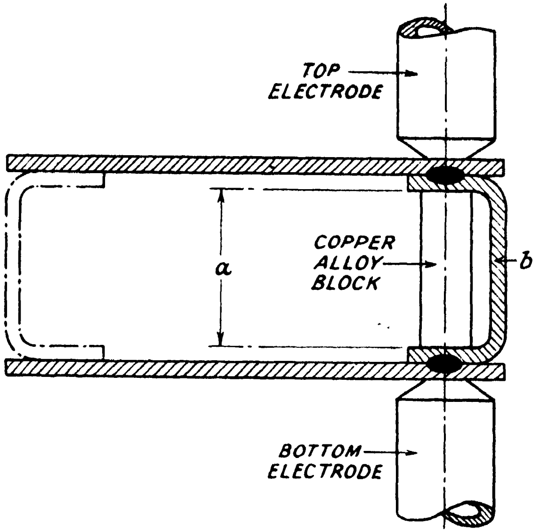


Fig. 11.11

---

[1] See A. J. Hipperson and T. Watson, "Resistance Welding in Mass Production," *Welding*, January–November 1947.

For spot welding, very simple arrangements may often be used. In the manufacture of box sections, multi-spot welding (see page 95) can be carried out in a standard spot welding machine by inserting a copper alloy block inside the component (Fig. 11.11). This arrangement, simple as it may be, gives, however, satisfactory results only if the distance *a* can be kept fairly accurate in the bending operation for component *b*.

When projection welding bosses to levers the base of the fixture, which acts as bottom electrode, must be insulated from the top platen, and locating V-block *a* and clamp *b* have to be made of insulating material, as they touch both boss *c* and lever *d* (Fig. 11.12). Locating pin *e* may be made of steel, as it comes in contact only with lever *d* itself.

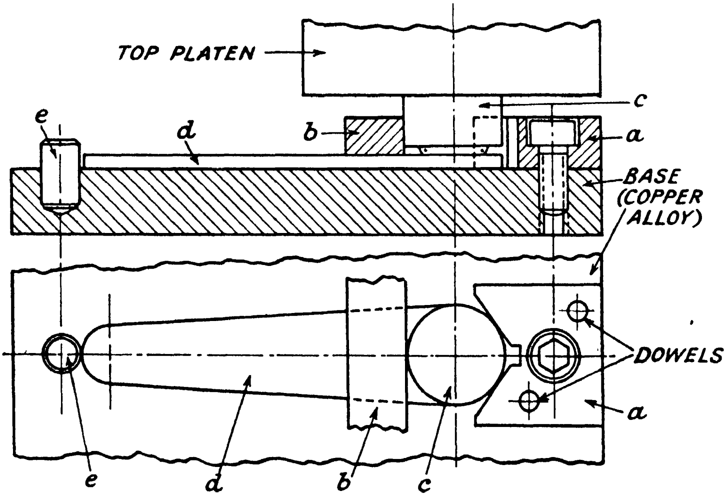


Fig. 11.12

Due to the high speed with which resistance welds are produced, fixtures must be designed such as to reduce handling times, loading and unloading of the fixture, to a minimum, as otherwise the ratio between welding time and handling time would become uneconomical.

A very simple and efficient projection welding fixture for welding angle brackets to rolled-steel angle sections (Fig. 11.13) is shown in Figs. 11.14–11.15. The brackets (*a*, Figs. 11.13, 11.15), with two projections in each, are held in the top platen by means of a clamp (*b*, Figs 11.14, 11.15), while the angle section itself is located by means of holes *c* and pegs *d* (Figs. 11.13, 11.14, 11.15) in the bottom structure

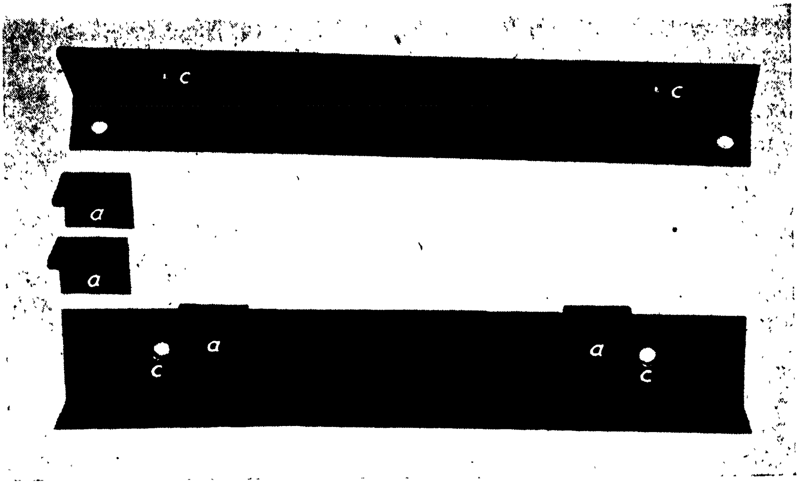


Fig. 11.13

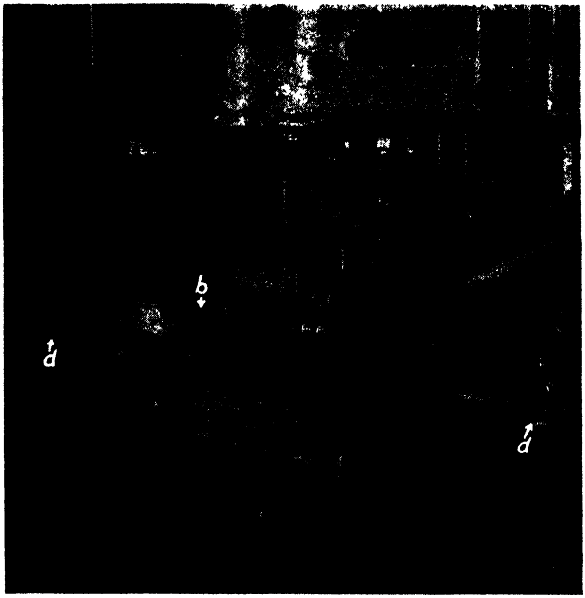


Fig. 11.14. Fixture for Projection Welding Angles (*Metropolitan-Vickers*)

of the fixture. The water-cooling arrangements for the top and bottom part of the fixture can be clearly seen in Figs. 11.14 and 11.15.

A great variety of typical fixtures for resistance welding is shown in the previously mentioned articles by A. J. Hipperson and T. Watson (see footnote on page 214).

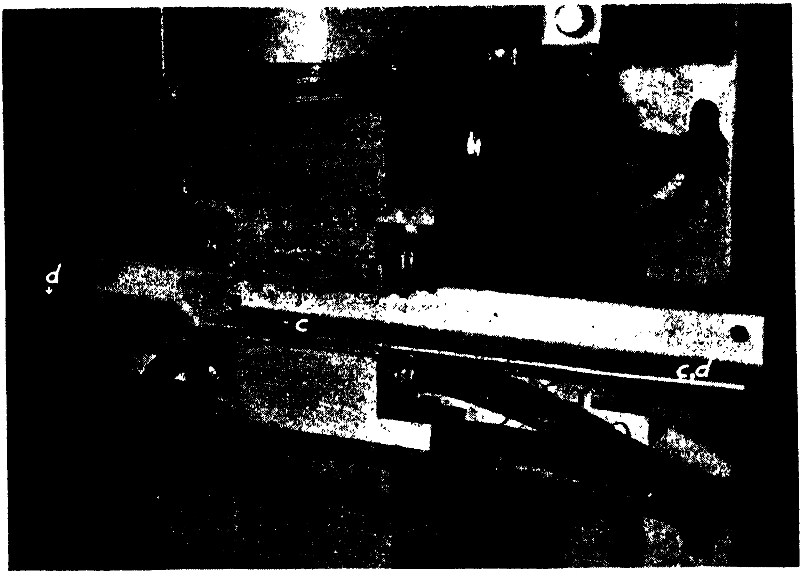


Fig. 11.15 (*Metropolitan-Vickers*)

CHAPTER XII

SAFETY PRECAUTIONS, PROTECTIVE AND WELFARE EQUIPMENT

WELDING operations, like many other manufacturing processes, may present various dangers to the operator unless adequate precautions are taken. Two important documents concerning safety measures in connection with welding plant and equipment have been issued by the Government Factory Departments.[1] They should be kept available for consultation in every shop.

Precautions against explosions have already been mentioned so far as the design and operation of gas-generating and storage plant is concerned (see page 129), and the following precautionary measures have to be taken in connection with the installation of such plants. Only special flame-proof electrical equipment should be used in buildings containing gas-generating or storing plant. Stores should be fireproof and should not be used for storing inflammable material. Fire-fighting equipment should be kept readily available. Oxy-acetylene generating and welding plant should be accommodated in places where either ample air space or good ventilation prevents the formation of explosive air-gas mixtures. Smoking and the use of open flames, other than the welding flame itself, should be prohibited, and a specified minimum distance must be maintained between gas-generating and storing plant and the nearest welding points.

Precautions in the design of electrical plant have also been described (see page 27). Regarding the installation of such plant, earthing arrangements should be such as to provide ample current-carrying capacity in order to avoid overheating of the earthing cables. The current-carrying section of the earthing conductor should be so much larger than that of the protective fuse wire so that the fuse blows before any damage will be done to the earthing cable. The connection between the work piece and earth should be made on a thoroughly cleaned surface of the material to be welded. Special care should be taken to prevent leakage of earthing currents through conductors other than those installed for the purpose, such as crane ropes, chains, and water or gas pipes. These may be subjected to heavy current loads in case the current-carrying capacity of the actual return cable is reduced or eliminated through mechanical failure of the earthing conductor.

---

[1] *Memorandum on Safety Measures Required in the Use of Acetylene Gas and in Oxy-acetylene Processes in Factories,* Form 1704, Factory Department, Home Office; *Memorandum on Electric Arc Welding,* Form 329, Factory Department, Ministry of Labour and National Service.

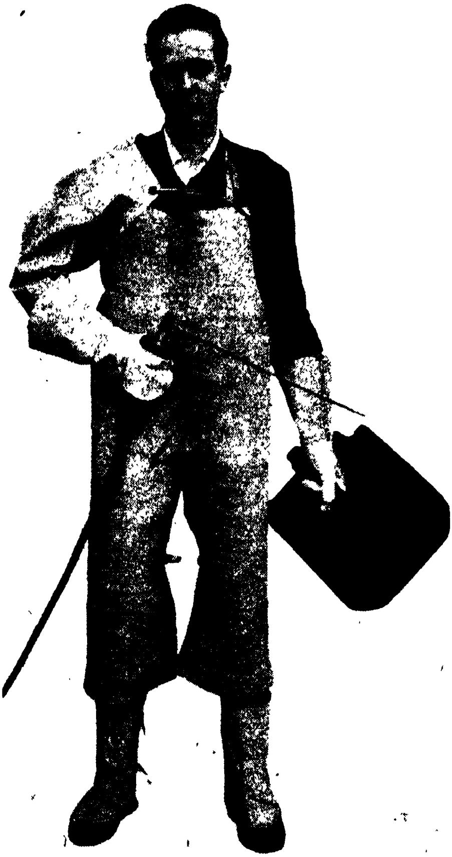


Fig. 12.1. Protection for Electric-Arc Welder (*Murex*)
Showing leather sleeves, mitt-type leather gauntlet gloves, split-type leather apron, screen, and leather gaiters.

Gas pipes should be particularly watched from this point of view as—in the case of leakages—sparks may cause explosions.

The earthing of work carried by manipulators presents a particular problem. If the earthing cable is connected to the manipulator stands and not to the table or to the work itself, the current has to be transmitted through the trunnion bearings which may offer considerable resistance and may, therefore, become unduly heated. Unless special earthing devices which by-pass the trunnion bearings are provided on manipulators, it is recommended to clamp the earthing cable directly to the work to be welded.

The health of welding operators may be affected by the welding heat, by flying sparks, by the light intensity of the welding flame or the arc, and by the radiations from the latter. Leather or asbestos gloves, aprons and protecting sleeves (Fig. 12.1) are recommended to protect the welder from the effects of the welding heat and from the danger of flying sparks. In order to protect the operator against the effects of fumes and hot gases developing during the welding process, the installation of fume extraction fans providing efficient ventilation is of the greatest importance. In addition, the use of respirators may be necessary, particularly during the welding of brass or of galvanized iron and when carrying out welding operations in confined or badly ventilated spaces.

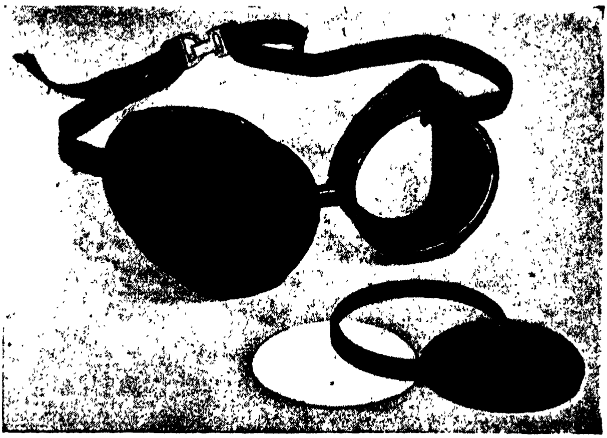
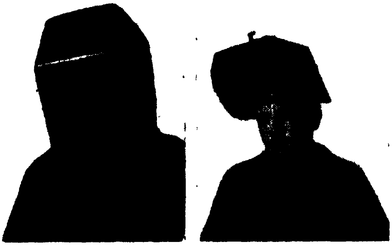


Fig. 12.2. Welding Goggles (*Safety Products*)

Most important of all is, however, the protection of the welder's eyes. Flying sparks may cause mechanical damage, and heavy eye strain may be caused, by the light intensity of the welding flame and, more so, by the electric arc. During gas-welding operations goggles with dark glasses (Fig. 12.2) give good protection against the intense light and against flying sparks. The frames of these goggles have to fit tightly against the welder's face in order to give mechanical protection to the eyes so as to make it impossible for flying particles to get even sideways behind the glasses. Those parts of the goggle frames which touch the skin should not be of metal but of a heat-insulating material which will not become warm and burn the skin. After a certain time in use the dark glasses become pitted by flying sparks and it should then be possible to replace them without difficulty.

In electric-arc welding, apart from the blinding effect of the arc-light and the danger of flying sparks, the ultra-violet and infra-red rays may affect the skin and the conjunctiva in the eye, causing effects similar to those found after over-exposure to sun rays at great heights. The effect on the eyes, called "eye flash" may be caused even by looking into the arc for a very short time only. It appears usually a few hours after the eye has been actually exposed to the arc. The symptoms are similar to those of conjunctivitis, and may vary from pain and watering of the eyes to even temporary loss of the eyesight and headaches. Carelessness or inexperience of the welder, e.g. when an arc is struck without the eyes being screened in time, can often be blamed for eye flash, but as the time of exposure to the arc causing eye flash is very short, even persons other than the welder may be affected if they happen to pass a place where welding operations are in progress. For this reason, all places in the works where arc welding is carried out should be screened. Although permanent effects on the eyes are not likely to occur, recovery from eye flash may require up to several days. Treatment consists usually of protection from light and application of cold water. Various mixtures of eye drops are used which reduce and heal the inflammation.[1]



a b

Fig. 12.3. Welder's Helmet (*Murex*)

The protective screens (see Fig. 12.1) or helmets (Fig. 12.3) generally used for arc welding offer good protection. The screens can be held in the free hand, one hand only being usually occupied in metal-arc welding. For arc welding operations which necessitate the use of both hands, i.e. operations using separate filler rods, such as carbon-arc welding, argon-arc welding, atomic-hydrogen welding, helmets (Fig. 12.3) are worn by the welder. These are hinged on a frame fitting on the welder's head, and—by a slight movement of the head—can be moved in the protective position (Fig. 12.3 a) or out of the way (Fig. 12.3 b).

---

[1] See *Memorandum on Electric Arc Welding*, Form 329, Factory Department, Ministry of Labour and National Service.

The viewing glasses used[1] not only prevent the blinding effect of the arc light but, through their radiation absorbing qualities, prevent the more or less serious effects of burning which may be caused by the ultra-violet and infra-red rays. As these glasses are usually fairly expensive, they are often protected by plates of plain glass, which can be changed when they are pitted by weld splashes.

Purely mechanical protection of the eyes is usually necessary when chipping off slag, and during resistance welding operations where sparking and splashing may occur, particularly when some dirt is burned away between plates to be welded. Plain glass goggles or plastic eye shields are worn in such cases.

---

[1] See B.S.S. 679.

CHAPTER XIII

PLANT MAINTENANCE

EFFICIENT maintenance of welding plant will contribute towards a high standard of safety and quality of the welding work.

Apart from keeping plant and equipment clean, little maintenance work is required for gas-welding plant, but great care is necessary when handling such plant, in order to prevent dangerous explosions (see page 129). Carbide is a poor heat conductor and may retain fairly high temperatures for a considerable time. Remainders of carbide taken out of generators on recharging should, therefore, not be re-used, as explosions may occur, and carbide baskets should always be carefully cleaned before being filled with fresh carbide.[1]

If repair work has to be carried out on acetylene generating plant, and particularly if hot tools or open flames have to be used, the greatest care is necessary to ensure that no acetylene is left in the part under repair. Before being thoroughly cleaned, such parts should be filled with water in order to displace all acetylene which might have been left. After cleaning, they should preferably be left filled with water for a few days before repair work is started. This precaution is also necessary when working on old plant, as traces of acetylene may even be found in plant which has been out of action for several years. At regular intervals generators should be painted as a protection against rust. Asphalt tar is usually used internally, and oil paint externally.

Hydraulic back pressure valves and their connections should be cleaned from time to time, and every day, before work is commenced, the water level should be checked in order to ensure that it is at the correct height. All gas connections, fittings and pipes should be periodically examined for leakages. Blowpipe nozzles should be cleaned free of metal and slag particles which may block their orifices. For cleaning the orifice only wire of soft material (soft copper) should be used, as hard material such as steel wire may enlarge the orifice and create dangerous conditions (see also page 144). Cleaning of the blowpipes and regulators and, if necessary, overhaul by the manufacturer should be carried out periodically.

---

[1] Form 1704, Factory Department, Home Office, already quoted.

Maintenance of arc welding plant[1] is usually carried out in the same way as that of general electrical plant in a factory.

Welding transformers are easy to maintain as they have no moving parts, and all that is necessary with oil-immersed transformers is to see that the oil is at the correct level. In air-cooled transformers the air passages should be cleaned at regular intervals, in order to prevent blocking up by dirt or dust. Compressed air blown through the air passages is the best means of cleaning these transformers. Examination of the contacts of rotary current selector switches is also advisable from time to time, as these contacts may become badly burnt if—mistakenly—the switch is operated while welding current is flowing.

All connections should be checked occasionally to ensure that loose contacts do not cause power losses in the welding circuit.

The maintenance of welding generators requires a bit more care because, due to the continuous rotary movement of the various parts, they are subjected to wear and tear. The lubrication of the bearings and the fit of the brushes in their guide boxes are two points which should be regularly looked after. Cleaning at regular intervals will prevent dust and dirt from accumulating in bearings, between commutators and brushes, and in the air passages. Nothing special need be said about the maintenance of starter and control gear, except perhaps that these, together with leads, welding cables, connections and insulations, particularly at the electrode holder, should be subjected to more frequent inspection than is the case in general engineering practice, because of the rougher handling to which they may be subjected in the welding shop.

The maintenance staff should also keep an eye on the sizes of welding cables used for various welding operations, to prevent overloading of the cables and excessive voltage drop and power losses due to cable sections being too small or cable lengths above the recommended values.[2] A periodic check of earthing arrangements should also be made (see page 218).

An important point in connection with the maintenance of metal-arc welding plant is the storage of electrodes. They should be kept in a dry place, as damp electrodes may be the cause of insufficient penetration and porous welds (see page 123). Different electrode types should, according to their properties, be kept carefully separated and should be issued to the welders as and when required for each job. Otherwise the temptation might be great for a welder, when he has some electrodes left over from a previous job, to use them on a new job for which they may be entirely unsuitable.

---

[1] See E. W. Harding, " Maintenance of Arc Welding Plant," *Welding*, January 1947.

[2] See B.S.S. 638.

Maintenance of resistance welding plant[1] requires a staff with more specialized knowledge than that in charge of the general electrical maintenance work in a factory. Control circuits of resistance welding machines, especially in the case of electronic controls, may be fairly complicated (see page 179), and without a thorough understanding of them, maintenance and repair work may be practically impossible.

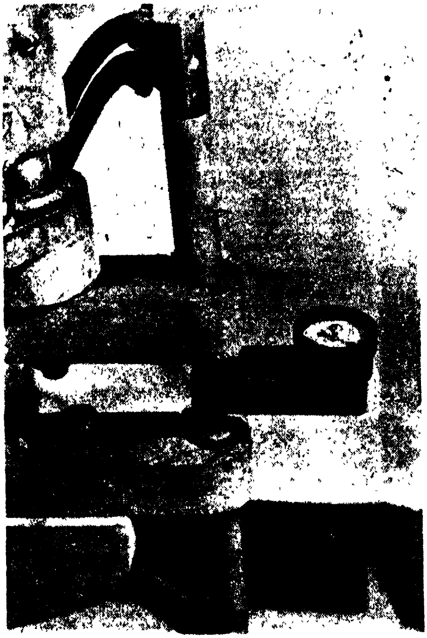


Fig. 13.1. Electrode Pressure Gauge in Spot Welding Machine (*B. & H. Welders Ltd.*)

Of the greatest importance is cleanliness, as mechanical losses due to friction, and electrical losses due to increased resistance, may be caused if dirt and dust or weld flash prevent parts of the machines from functioning satisfactorily. The quality of resistance welds depends upon electrode pressure, current setting and current density, and timing of the welding operation (see page 77). The maintenance staff have to concentrate their efforts, therefore, on the parts which control these conditions. The mechanism producing the welding pressure must be kept in a state of high efficiency. In the case of pneumatic or hydraulic pressure control, leakages should be eliminated, packing, gaskets and glands inspected periodically, the fit between rams and cylinders checked. Periodical lubrication of all moving parts will reduce friction losses, and a check of the actual electrode pressures by means of pressure gauges (Fig. 13.1) which can be inserted between the electrodes, will ensure that the required pressures as set with the adjusting devices and as read on the indicators are obtained for the various welding operations.

---

[1] See C. A. Burton, "The Power Supply, Installation and Servicing of Resistance Welding Machines," *Sheet Metal Industries*, November 1945.

Pressure-tight joints must also be maintained in the pneumatic and hydraulic clamping devices used on flash-butt welding machines, as losses of clamping pressure may result in slipping of the components under the upset pressure; and leakages in the cooling water system must be eliminated to prevent possible overheating.

To prevent power losses and reduction of welding currents, electric connections and contactors require the usual care, especially as far as cleanliness is concerned and—as correct current density is essential in spot welding operations—mushroomed electrode tips have to be trimmed, to keep the tip size within the permissible limits (see page 79). Trimming should be done by proper machining operations and not by hand-filing, as the correct shape must be maintained for satisfactory welding conditions. Trimming of electrodes while in the spot welding machine should only be carried out if a specially designed hand cutting tool is available. Replacement of worn electrodes by correctly machined ones which are taken from stock gives, however, the most satisfactory results.

With seam welders special care is required in the lubrication of the electrode wheel bearings, for which high quality graphite grease or castor oil is recommended,[1] as ordinary greases may create difficulties due to their insulating quality.

The timing devices in modern resistance welding machines usually need very little maintenance, apart from periodical checking of the relays, cleaning of contacts, and elimination of loose connections.

---

[1] See C. A. Burton, "The Power Supply, Installation and Servicing of Resistance Welding Machines," *Sheet Metal Industries*, November 1945.

CHAPTER XIV

DISTORTION AND RESIDUAL STRESSES

ONE of the most difficult problems encountered in fabrication by welding is the fact that, due to the concentrated heat applied in the various parts of the structures under construction, distortions are caused, and that, if this distortion is prevented by the stiffness of the structure itself or by stiffeners inserted for the purpose, internal stresses are created.

During the welding operation heating and cooling of the affected material takes place. While the temperature of the greater part of the parent material will not be affected by the welding process, the weld metal itself and the parent metal adjacent to it are subjected to a considerable change in temperature, being raised to the temperature of the molten state and lowered again to that of the surrounding atmosphere. Whilst, however, in the molten state the material is free to move, adjusting itself according to the prevailing conditions, it will tend to shrink during the cooling period and to pull all the other material with it when shrinking. According to the structural conditions, the parent material will either follow the shrinking movement of the molten metal, i.e. distortion will occur, which may later have to be eliminated by stretching and consequent stressing, or it will resist this distortion, i.e. it will be internally stressed. The third alternative is, of course, that either the weld or the parent material will be overstressed and will crack.

Three ways of tackling the problem are open to the welding engineer. These are:

1. To anticipate distortions likely to occur and either to design and arrange the components or to devise the welding procedure, in such a way that, after the welding operation is completed, the finished structure will be of the required shape.

2. To counteract distortion by applying the welding or flame-cutting heat in such a way as to balance the effect of thermal distortion, or to counteract artificially, through suitable preheating, one distortion by another which reduces the resultant distortion in the correct proportion.

3. To prevent distortion by mechanical means such as stiffeners, struts or the inherent stiffness of the structure as designed. This will, however, result in the creation of internal stresses which may or may

not be detrimental to the functioning of the structure, and which, in the former case, must be reduced below permissible values by adequate heat treatment.

A typical example of distortion during fusion welding occurs when two flat plates are butt welded together (Fig. 14.1a). While starting the welding operation with a gap of equal width between the plates over their whole length, progressive contraction of the weld metal during the welding operation will close the gap so that finally the plates will be in a relative position to each other as shown in Fig. 14.1b.

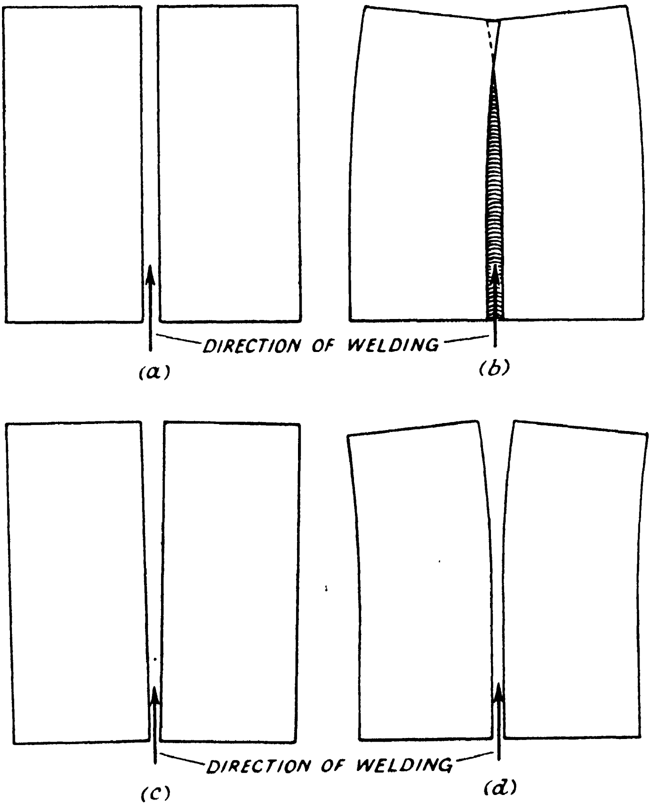


Fig. 14.1

When preventing such overlapping movement by tack welding the plates at short intervals, there is, particularly in the case of very thin sheets, a danger of warping and buckling caused by the stresses which are set up by preventing the free movement of the plates.

For the simple case shown in (a) and (b) the amount of distortion can be anticipated approximately, and the plates can be laid out with a gap that widens in the direction of welding, i.e. a gap which is narrow at the starting point and widens towards the finishing point of the weld (Fig. 14.1c). This is often done by means of alignment clamps, especially when welding longitudinal joints of cylindrical shells (Fig. 14.2).

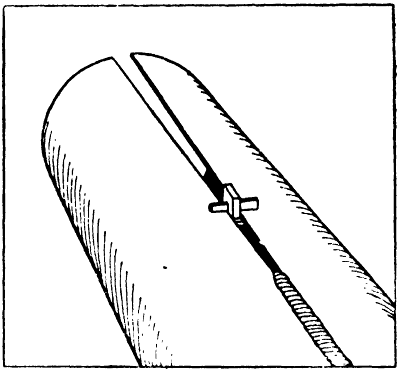


Fig. 14.2 (*B.O.C.*)

Table 36 shows typical values of tapered gaps which allow for such distortion. It must be considered, however, that the plate thickness and the welding speed may necessitate variations of the values shown. The amount of distortion is controlled to a large extent by the quantity of heat put into the work at a given time, distortion can, therefore, be reduced by applying higher welding speeds, e.g. in the case of arc welding by using large-size electrodes.

TABLE 36

Average Values for Longitudinally Tapering Gaps when Oxy-Acetylene Welding Butt Joints of Flat Plates

Material	Longitudinal taper of gap between plates inches per foot
Steel	$\frac{1}{4}-\frac{3}{8}$
Brass and bronze	$\frac{3}{16}$
Monel metal	$\frac{3}{8}$
Aluminium	$\frac{1}{8}$

Because of the higher welding speeds obtainable distortions caused in arc welding are usually smaller than those caused in oxy-acetylene welding but the problem remains the same in principle, i.e. the application—in a satisfactory way—of the maximum amount of heat in a minimum time. If the slight curvature at the end of the plate edges (see Fig. 14.1 b) is undesirable, the plates can be flame-cut to such a shape (Fig. 14.1 d) that the resulting edges will be straight. In this case, however, the exact amount of curvature will usually have to be found by trial and error.

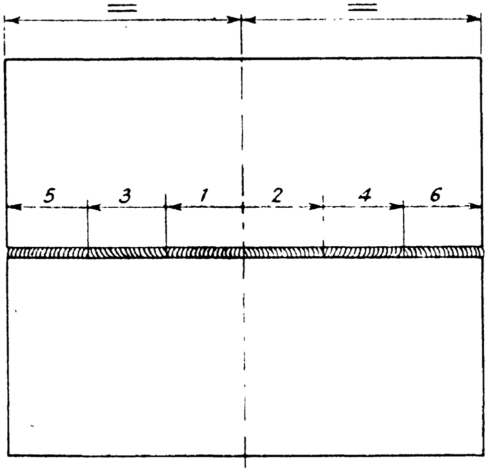
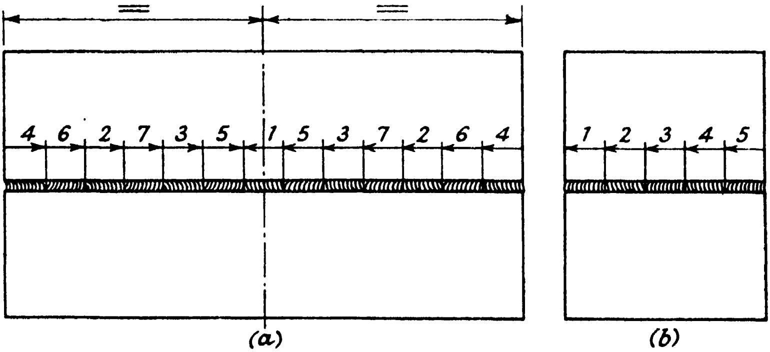


Fig. 14.3



(a) (b)

Fig. 14.4

If the gap has to be parallel from the start, staggered, or stepped welding is a method used for preventing distortions. A simple reverse welding method (Fig. 14.3) a specially planned welding sequence

(Fig. 14.4a)[1] or a "step back" welding sequence (Fig. 14.4b)[1] or similar procedures are often effective in such cases.

The problem becomes more difficult if the structure resists expansion or contraction through its inherent stiffness. In the case of the frame (Fig. 14.5) the hot weld metal will fill the gap at (a) and the welding heat will bring to a temperature near that of the weld metal only the metal directly adjacent to the weld. After the gap has been filled under these conditions the hot metal will contract and will thus pull the frame into the shape shown by the dotted lines, causing tensile stresses in the weld and compression stresses in the outer members (b) and (c). Even if the weld does not crack under the tensile stress, a possibility which may be aided by the fact that the tensile strength of steel at high temperature is much lower than it is at normal room temperature the resultant internal stresses may not be permissible in the structure. By preheating members (b) and (c) prior to starting the welding operations these will be artificially expanded and, when allowed to cool down after the welding operation is completed, they will contract at a rate similar to that of the weld. The distortion and internal stresses will then be, at least, reduced to a tolerable value.

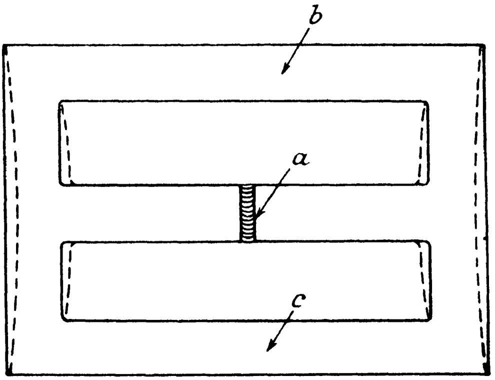


Fig. 14.5

The distortions discussed up to now take place mainly in the plane of the plates concerned, and any distortion in other planes, such as buckling of thin plates, is only a secondary result of the former. This was the case because we could assume equal contraction through the depth of the weld, as would be the case when butt-welding plates with square, unprepared edges, where the width of the weld, and with it the width of the heat-affected zone is fairly constant throughout the thickness of the plates.

---

[1] See *Recommendation for the Application of Electric Arc Welding to Ship Construction*, issued by the Admiralty Ship Welding Committee.

Conditions become different, however, when we consider V- or U-butt welds, and fillet welds.

In the case of prepared butt welds the amount of metal contracting during the cooling period increases towards the open side of the V or U, and the plates will be lifted as shown in Fig. 14.6a, unless they are restrained and become stressed.

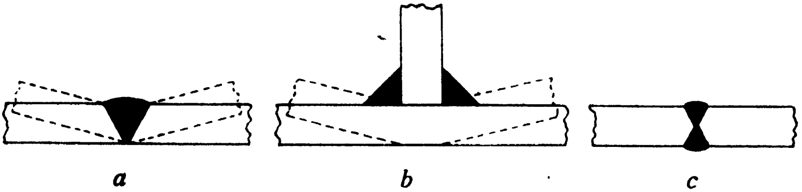


Fig. 14.6

Similar conditions exist in the case of fillet welds (Fig. 14.6b). Symmetrical arrangement of welds (Fig. 14.6c) and simultaneous welding on opposite sides will reduce the distortions shown in Fig. 14.6a.

To keep distortions and stresses low, the amount of weld metal deposited in a joint should be reduced to a minimum, i.e. gaps should be small, and weld metal should not, so far as possible, be employed for filling gaps caused through faulty plate preparation. Greatest care in plate preparation will usually compensate through reduced stresses and distortions. Furthermore, a maximum amount of weld metal should be deposited in a minimum amount of time, thus reducing the heat input. The use of heavy gauge arc-welding electrodes, besides resulting in shorter time and lower labour cost, will also keep distortions and stresses low. The increased impact strength of welds deposited with a greater number of small runs (see page 43) will only be required in certain special cases which are an exception to the rule.

Conditions similar to those found with welding will be encountered with flame cutting.[1] The metal already cut is contracting whilst the metal just to be cut, i.e. the material ahead of the cutter, is expanding. In the case of cutting along a straight line the distortion produces an effect similar to that encountered when butt welding two plates along straight edges, i.e. the parts begin to overlap towards the end of the cut and produce the so-called " scissors effect ", (see Fig. 14.1b). As this effect becomes greater near edges than it does in the middle of a plate, distortion will be reduced to a minimum if the portions near edges are cut last, i.e. if the component to be cut remains attached to the plate as long as possible.[1]

---

[1] See E. Seymour Semper, " Oxygen Cutting," *Welding*, November 1946.

Distortions caused by heat expansion can be reduced artificially by limiting the amount of metal which is being heated through the welding process. This is done by chilling the portion of the parent material outside and near the zone to be actually welded, thus localizing the heat to that zone. The application of metal chills (Fig. 14.7) or other chilling material, or of water-jet arrangements which spray the zone around the weld with cooling water, is usually found in connection with gas-welding processes, as in arc welding the heat is already more concentrated. It should be noted, however, that chilling, whilst reducing distortion, will usually increase internal stresses.[2]

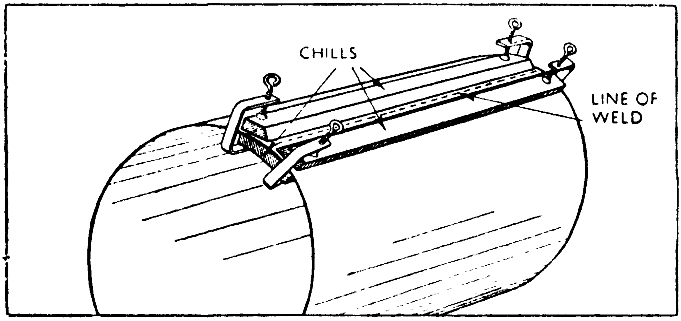


Fig. 14.7 (*B.O.C.*)

There are cases, especially in the manufacture of welded machinery structures, where even small distortions during the welding assembly procedure are undesirable and have to be prevented. Stiffeners and struts have to be inserted in such cases, or, if the structures are produced in large quantities, suitable clamping jigs (Fig. 14.8) may be applied, which hold the parts in correct relation to each other until the stability of the completed structure prevents any movement of the stressed parts. If, however, distortions are prevented in this way, there is a probability of internal stresses, and this should be taken into consideration. While in certain cases internal stresses may not have a detrimental effect on the strength of a structure, they may weaken it considerably if stress raisers such as notches or abrupt discontinuities of shapes may cause stress concentrations, particularly in structures which are likely to be subjected to fatigue loading conditions.[1]

---

[1] See E. Seymour Semper, op. cit.

[2] See A. E. Berriman, "Controlling the Effect of Contraction and Included Stresses in Welded Structures," *Transactions of the Institute of Welding*, April 1942.

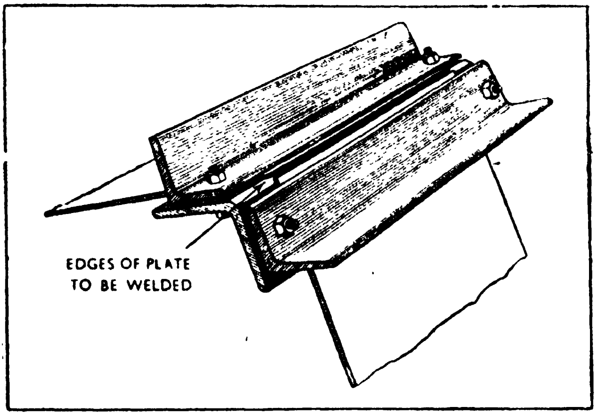


Fig. 14.8 (*B.O.C.*)

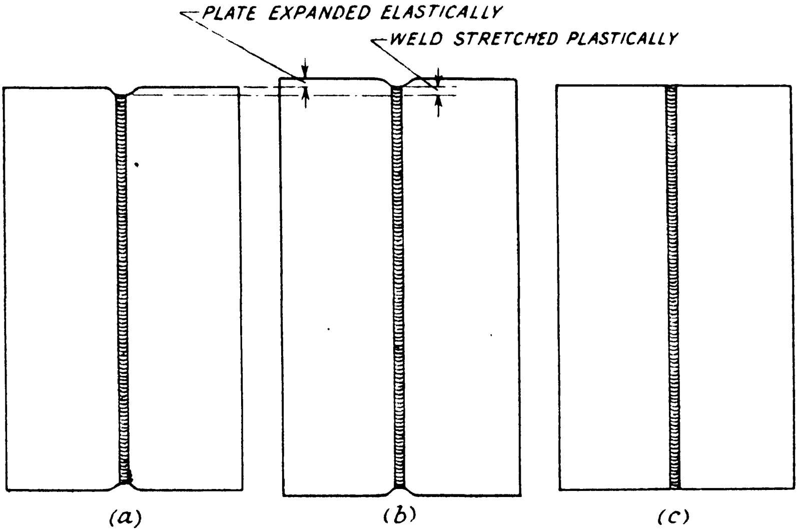
Internal stresses are also undesirable in structures requiring great working accuracy, such as machine tools, jigs and fixtures, high speed gear boxes, because they may cause movement or distortion during manufacture, particularly during machining operations, or later "creeping" in service during the working life of the structure in question. Not only structures which fall under the above-mentioned categories, but also pressure vessels and similar structures where failure would be dangerous to human life, and containers of certain chemicals where stress corrosion cracking is likely to occur, should be subjected to a stress-relieving heat treatment which will remove the internal stresses to a reasonable degree. Experiments have shown[2] the influence of the heat-treatment temperature upon the degree of stress relief, and it has been proved that below 550°C. no effective relief of internal stresses can be expected. The temperature generally accepted for stress-relieving heat treatment of mechanical engineering structures is 600–650°C., and in order to avoid new stresses developing through too rapid cooling after heat treatment, it is recommended not to open the furnace doors before the temperature has dropped to 300°C. in the case of general engineering structures, and to 100°C. in the case of high precision structures.

---

[1] See *Heat Treatment of Welded Constructions in Mild Steel.* Recommendations prepared by the Committee on Heat Treatment of Welded Constructions, The British Welding Research Association; also J. Orr, "Strength of Welded Constructions: Experiments on the Effect of Residual Stress," *Welding,* November 1945.

[2] L. E. Benson and H. Allison, "The Low Temperature Annealing of Welded Mild Steel Structures to Relieve Internal Stresses," *Welding Symposium, Iron and Steel Institute,* May 1935. J. R. Stitt, "Stress Relief of Weldments for Machining Stability," *American Welding Journal,* June 1945, January 1946.

The soaking time, i.e. the time during which the temperature in the furnace has to be kept at 600–650°C., has to be long enough to bring all parts of the heat-treated structure to the above temperature. Detailed specifications for various cases of structures to be heat treated can be found in the above recommendations (see page 234).



(a) (b) (c)

Fig. 14.9

An interesting method of relieving longitudinal stresses in long fusion welded seams has been developed in U.S.A. where the problem became acute during the welding of ship structures. It was found[1] that the zone adjacent to a long welded seam was highly stressed (the stress in the weld being around yield stress) longitudinally through the longitudinal contraction of the weld metal when cooling (Fig. 14.9 a).[1]

---

[1] T. W. Greene and A. A. Holzbaur, "Controlled Low-temperature Stress Relieving," Welding Research Supplement, *Welding Journal*, March 1946.

When stretching plate and weld material longitudinally by such an amount as to bring the contracted weld metal to the original length of the plate (Fig. 14.9 b),[1] the stretch in the weld would be plastic, the stress being above the yield stress, whilst the plate material, being stressed below its elastic limit, would spring back to its original length after being released. Thus, after completion of the stretching operation, weld and plate material would be of equal length and free of longitudinal stresses (Fig. 14.9 c).[1]

This stretching operation is carried out by heating the plate material up to a temperature which causes expansion equal to the required amount of stretching, whilst the weld metal is kept colder and is, therefore, mechanically stretched by the surrounding plates.

It has been found, that the required temperature difference between plate and weld metal must be about 120°C. and as it is impossible to keep the weld down to room temperature during the process, the plate material is heated up to about 175–200°C. The operation is carried out by two sets of flame jets, one on either side of the weld, and followed by water jets which cool down the plate immediately after heating, thus preventing the plates from overheating and distortions. Experiments have shown[1] that nearly complete relief of longitudinal stresses could be obtained, provided flame and cooling water jets and process speeds were set to create optimum conditions.

---

[1] T. W. Greene and A. A. Holzbaur, "Controlled Low-temperature Stress Relieving," Welding Research Supplement, *Welding Journal*, March, 1946.

CHAPTER XV

WELD STRENGTH AND WELD FAULTS, AND SOME NOTES ON THE TESTING OF WELDS AND WELDERS

THE critical section of *fusion welds* is the " throat section " which is the minimum section along the weld passing through its root. In the case of a butt weld the " throat thickness " is considered equal to the thickness of the thinnest plate joined by the weld (see Fig. 15.2 a). In the case of a 45° fillet weld the " throat thickness " equals the leg length divided by $\sqrt{2}$ (see Fig. 15.2 b). The throat section which carries the maximum stress is determined by the product of throat thickness and effective length of the weld, the effective length being considered as the length of weld over which the throat thickness is maintained at its full value. For instance considering crater formation at the beginning and end of fillet welds, an allowance of twice the leg length is usually made, so that the effective length of a fillet weld is generally taken as the full length less twice the leg length (B.S.S. 538).

Apart from considering the actual stress-carrying area it must be remembered, particularly in case of fatigue loading, that the shape of fillet welds favours the creation of stress concentrations at the toes and at the root of the weld, a danger which exists in butt welds, only if the reinforcement (see Fig. 15.2 a) is not removed. Furthermore the surface of the weld and its shape, particularly the blending in with the surface of the plate, have an influence on the fatigue strength of the welded joint.[1]

The strength of the weld metal under static loading is usually considered to be about equal to that of the parent material. For establishing permissible stresses due allowances have to be made for the conditions created by the shape of the weld, e.g. the fact that the stress distribution in fillet welds is not uniform, and that fillet welds are always stressed in shear and bending due to the eccentric load application which is typical for them.

The permissible working stresses for fusion welds in 28/32 tons mild steel under the static loads have, therefore, been established as follows (B.S.S. 538):

---

[1] See A. Thum and A. Erker, " Dauerfestigkeit von Kehl- und Stumpfnahtverbindungen " (Fatigue Strength of Fillet and Butt Welded Joints), *Z.d. V.D.* I, September 1938.

(*a*) *Butt welds:*

Permissible tensile and compression stress	8 tons per sq. in.
Permissible shear stress	5 tons per sq. in.

(*b*) *Fillet welds:*

End fillets in lap joints	7 tons per sq. in.
All other fillet welds	5 tons per sq. in.

(*c*) For J—or bevel butt welds (see Figs. 2.28 a and 2.28 b), either single or double, only 75 per cent of the stresses mentioned under *a* are permissible.

With regard to fatigue-loading conditions permissible stresses have not yet been laid down, but the American Welding Research Council of the Engineering Foundation have established so called " dependable stresses ", i.e. ultimate fatigue stresses which can be assumed to apply in all cases of welded joints produced under normal workshop conditions with the care usually required for a quality welding job (Figs. 15.1a, 15.1b, 15.1c).[1]

Considering all the above points the actual strength of a welded joint depends upon its type, size, and shape, upon the quality and condition of weld and parent material, and, particularly in the case of fusion welded non-automatically produced welds, upon the human element, i.e. the skill and reliability of the welder.

Apart from maintaining the welding plant and equipment in a high state of efficiency (see page 223) and ensuring that correct materials and suitable procedures are employed, it is important, therefore, to select carefully the welders who are to carry out work on important jobs. A careless welder whose work is not watched by a supervisor who is guided only by technical considerations may spoil a job by not executing his work to the required standard. This is of particular importance, because the weld does not allow the same easiness of inspection with regard to soundness and efficiency, as does machine shop work where by means of " go " and " no go " gauges work may be either passed or rejected.

Apart from competent supervision—it is recommended that there should be one supervisor for every six welders—each welder's reliability should be tested from time to time by means of test pieces which he has to submit. Specifications to this effect have been issued

---

[1] *Fatigue Strength of Butt Welds in Ordinary Bridge Steel,* Report No. 3 of Committee on Fatigue Testing (Structural). *Fatigue Strength of Fillet, Plug, and Slot Welds in Ordinary Bridge Steel,* Report No. 4 of Committee on Fatigue Testing (Structural).

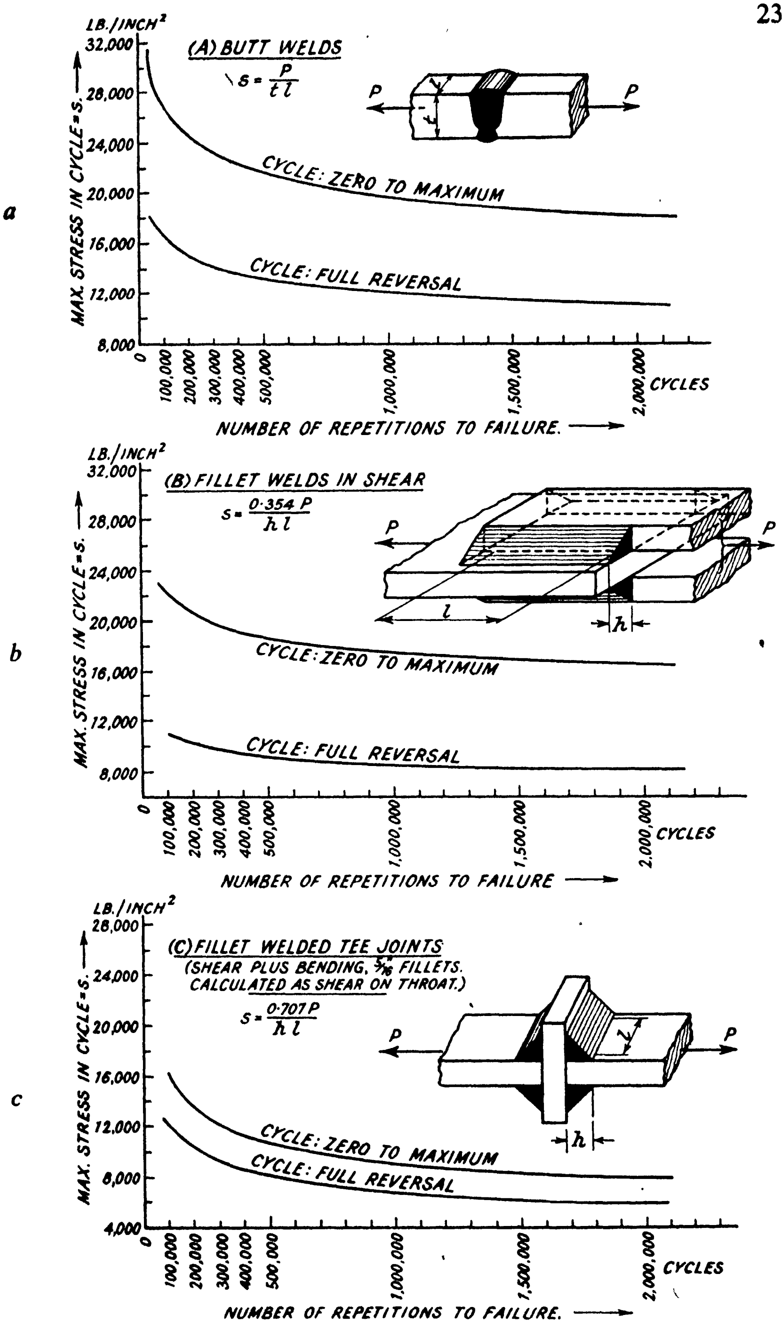
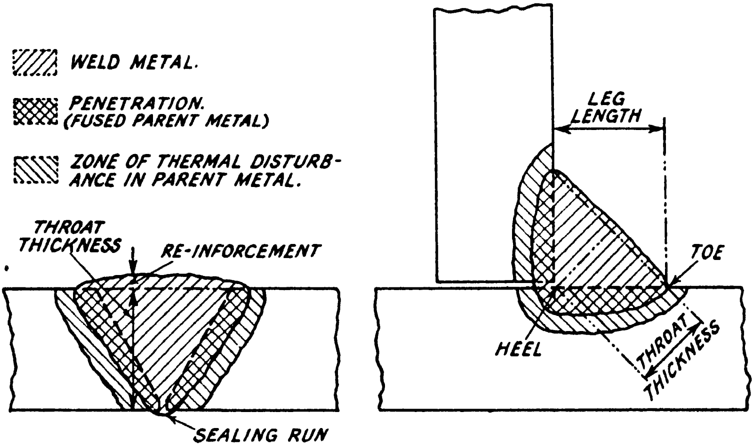

a
LB./INCH²
(A) BUTT WELDS
S = P/tl
P
P
t
CYCLE: ZERO TO MAXIMUM
CYCLE: FULL REVERSAL
MAX. STRESS IN CYCLE = S.
32,000
28,000
24,000
20,000
16,000
12,000
8,000
0
100,000
200,000
300,000
400,000
500,000
1,000,000
1,500,000
2,000,000
CYCLES
NUMBER OF REPETITIONS TO FAILURE.
b
LB./INCH²
(B) FILLET WELDS IN SHEAR
S = 0·354 P/hl
P
P
l
h
CYCLE: ZERO TO MAXIMUM
CYCLE: FULL REVERSAL
MAX. STRESS IN CYCLE = S.
32,000
28,000
24,000
20,000
16,000
12,000
8,000
0
100,000
200,000
300,000
400,000
500,000
1,000,000
1,500,000
2,000,000
CYCLES
NUMBER OF REPETITIONS TO FAILURE
c
LB./INCH²
(C) FILLET WELDED TEE JOINTS
(SHEAR PLUS BENDING. 5/16 FILLETS. CALCULATED AS SHEAR ON THROAT.)
S = 0·707 P/hl
P
P
l
h
CYCLE: ZERO TO MAXIMUM
CYCLE: FULL REVERSAL
MAX. STRESS IN CYCLE = S.
28,000
24,000
20,000
16,000
12,000
8,000
4,000
0
100,000
200,000
300,000
400,000
500,000
1,000,000
1,500,000
2,000,000
CYCLES
NUMBER OF REPETITIONS TO FAILURE.

Fig. 15.1

by various authorities[1] for work under their supervision and responsibility, and a British Standard Specification[2] has been published to cover welded constructions in general.

A brief survey of the possible weld faults and their causes may be permitted. in order to show when the full strength of a weld may or may not be expected.

Apart from chemical or metallurgical faults in the weld metal due to the use of wrong filler material or the employment of an incorrect welding procedure (see pages 103–128), fusion welded joints will not develop their full strength unless: 1. Satisfactory penetration is achieved. 2. The welds are of the correct shape. 3. No undercuts weaken the parent metal at the joint face. 4. No inclusions of slag or other foreign elements or blow holes interrupt the homogeneity of the weld metal. 5. No cracks exist in the weld. These points, will now be discussed in detail.[3]



(a) (b)

Fig. 15.2

The weld metal and the parent material affected by the welding process can be divided into three zones which can usually be clearly seen in a polished and etched section through the weld. They are the actual weld metal zone, the zone of weld penetration consisting of the parent metal which has been fused during the welding process, and the zone which, although not fused, has been affected by the welding heat. Fig. 15.2a shows these zones for the case of a V-butt weld and Fig. 15.2b for that of a T-joint fillet weld.

---

[1] Admiralty, Lloyd's Register of Shipping, British Corporation, and others.

[2] B.S.S. 1295, *Tests for use in the Training of Welders.*

[3] See F. S. Dever, "Weld Defects, Their Causes and Prevention," *Welding,* February 1947.

The metallurgical changes in the material structure of the heat affected zone have been discussed before (see page 103). The amount of penetration influences the strength of the connection between weld and parent metal, and the size of the load-carrying section of the weld. If the heat applied is insufficient to melt the parent metal to a satisfactory depth, too little (Fig. 15.3a) or no (Fig. 15.3b) penetration will result. In the case of metal-arc welding such lack of penetration (Fig. 15.3c) (see also Figs. 15.7, 15.8) can usually be attributed to too low a current setting in the current supply, unless the electrode for the first run was not small enough to reach down to the root of the weld (Fig. 15.3d). In the case of double-sided butt welds produced with deep penetration electrodes (see page 49) unsatisfactory penetration may result if the welds are not located opposite each other (Fig. 15.4a).

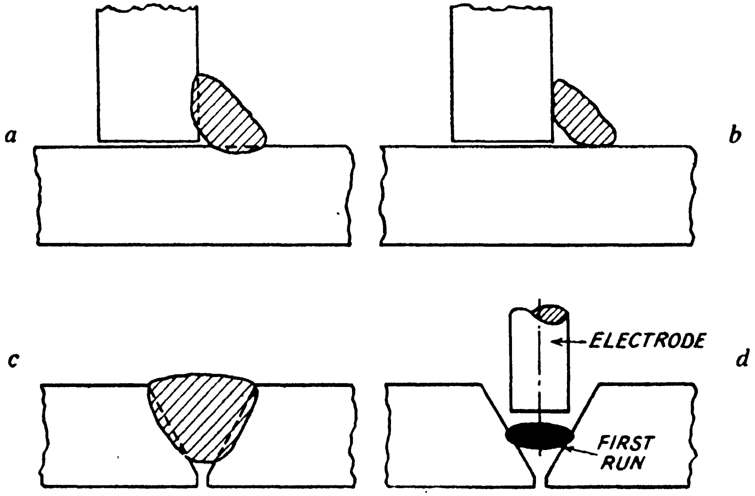


Fig. 15.3

Incorrect shape of the weld is often due to the use of unsuitable electrodes, such as may be the case when slag traps are caused by electrodes forming convex welds in intermediate runs (Fig. 15.4b). Bad procedure or manipulation may cause too weak (Fig. 15.4c) or unsymmetrical fillet welds (Fig. 15.4d). Excessive weld deposits may be due to incorrect current settings, travel speeds, or electrode manipulation.

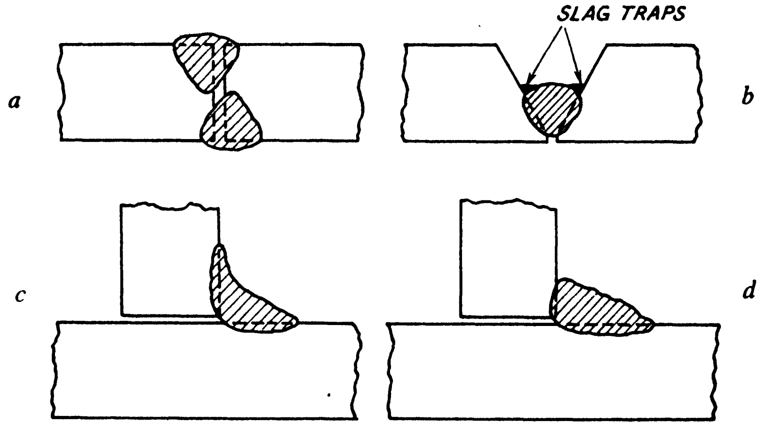


Fig. 15.4

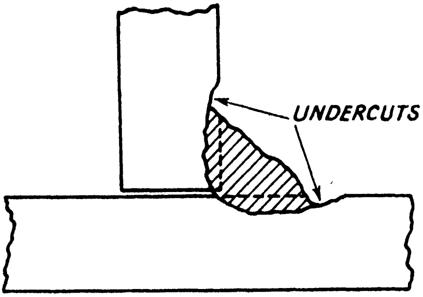


Fig. 15.5

The formation of undercuts (Fig. 15.5) is particularly undesirable, as it reduces the plate section at a part where metallurgical changes may already have increased the brittleness of the parent material. Undercuts are usually due to excessive welding current which melts a relatively large amount of parent material and causes it to sag under its own gravity, the crater not being filled because of too high a rate of travel of the electrode.

If the electrode is not held at the correct angle in relation to the parent plates, one-sided undercut may be caused through the heat being too much concentrated on one side of the joint. Undercut may also be produced if the molten metal can flow away under the action of gravity, due to bad positioning of the component plates (see page 46).

Excessive current or too low a welding speed may result in burning through the plates, with resulting component oxidization which is particularly undesirable in stainless steel welds.

Weld spatter may cause stress raisers outside the welded zone, wherever the splashes of electrode material stick to the parent metal.

Cracking of welds due to faulty procedure has been mentioned before (see page 46).

Slag inclusions and blow holes reduce the effective sectional area of the weld and, therefore, its load-carrying capacity. Carelessness in slag removal (see page 39) prior to putting down a new layer of weld when producing a multi-run seam may be the cause, or inaccessibility of the slag due to " slag traps ", i.e. badly designed or produced welds. Convex shape of the weld layer (see Fig. 15.4 b), bad direction of the arc ahead of the weld, too low welding heat may cause slag inclusions (see Figs. 15.9, 15.10). These defects can only be repaired by chipping or gouging out the affected portion of the weld and re-welding it.

Undercuts, bad penetration, slag or flux inclusions, may also occur in gas welding, and the causes are similar to those encountered in arc welding, as, for instance, incorrect heat input, unsuitable welding speed, bad manipulation, carelessness in cleaning plate and weld material.

It will be appreciated that the above-mentioned faults which affect the strength and reliability of the welds are more or less all caused by either lack of care or lack of skill on the part of the welder, and this skill and reliability are usually judged by bending, breaking and examining test pieces made by the welders, in accordance with the specifications mentioned before (see page 240). If a welder consistently produces good test pieces, he can be expected to produce equally consistently satisfactory and reliable welded joints in the actual structures on which he is working.

Among the methods used for the testing of welds a clear distinction must be made between testing on a scientific basis for the establishment of fundamental principles (see page 238) and routine testing of weld quality in the welding shop.[1] Among the latter may be mentioned the tensile test of butt welded bars (Fig. 15.6a) where, in a satisfactory weld, fracture should occur outside the weld in the parent metal, the bend test of butt-welded bars (Fig. 15.6b) where no sign of fracture should occur up to a bending angle of 120°, and the bend test of fillet welds (Fig. 15.6c) where the fracture shall show complete fusion, good penetration, and no slag inclusions or blow holes.[1]

---

[1] See H. N. Pemberton, "The Testing of Welds," *Transactions of the North East Coast Institution of Engineers and Shipbuilders*, 1942, p. 205.

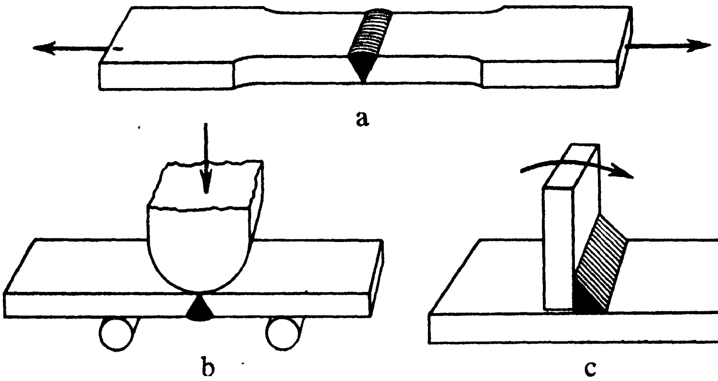


Fig. 15.6

Among the non-destructive tests of welds in a completed structure, magnetic crack detection and X-ray examination[2] are widely used (see Figs. 15.7–15.10).[3]

Whilst considerations similar to those mentioned in connection with fusion welded butt joints apply to the strength of butt joints produced by the resistance welding process (flash butt welding), conditions are different in the case of spot and projection welded joints. These should always be arranged in such a way as to be stressed in shear. Tensile loads create a tearing effect on the welded joint and do not give the reliable strength characteristics required in a working joint. Experiments have shown that for welds in mild steel (28–32 tons per square inch, with less than ·2 per cent C), 20 tons per square inch is a reliable ultimate shear stress value for spot and projection welds under static load. With a recommended safety factor of 4, the permissible shear stress is 5 tons per square inch.[1]

---

[1] See B.S.S. 1295.

[2] See E. Fuchs, L. Mullins, and S. H. Smith, " Inspector's Approach to Radiographs of Mild Steel Butt Welds," *Transactions of the Institute of Welding*, February 1947; and " Standardization of the Radiographic Examination of Welded Joints in Mild Steel Pressure Vessels," *Recommendations of the FE. 6 Committee on Radiography of Pressure Vessels*, of the British Welding Research Association.

[3] These figures, taken from the before-mentioned paper by Fuchs, Mullins, and Smith, have been kindly put at the author's disposal by E. Fuchs, Esq., one of the authors.

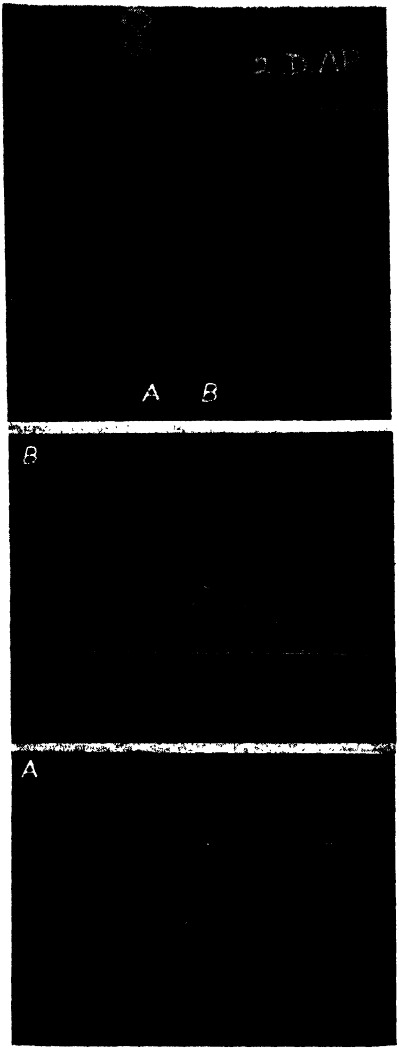


Fig. 15.7. ½″—60° Double Vee Weld showing lack of penetration and some slag inclusions. Above: X-ray Photograph indicating respective sections

---

[1] See *Welding Memorandum* No. 4c, Advisory Service on Welding, Ministry of Supply, London.

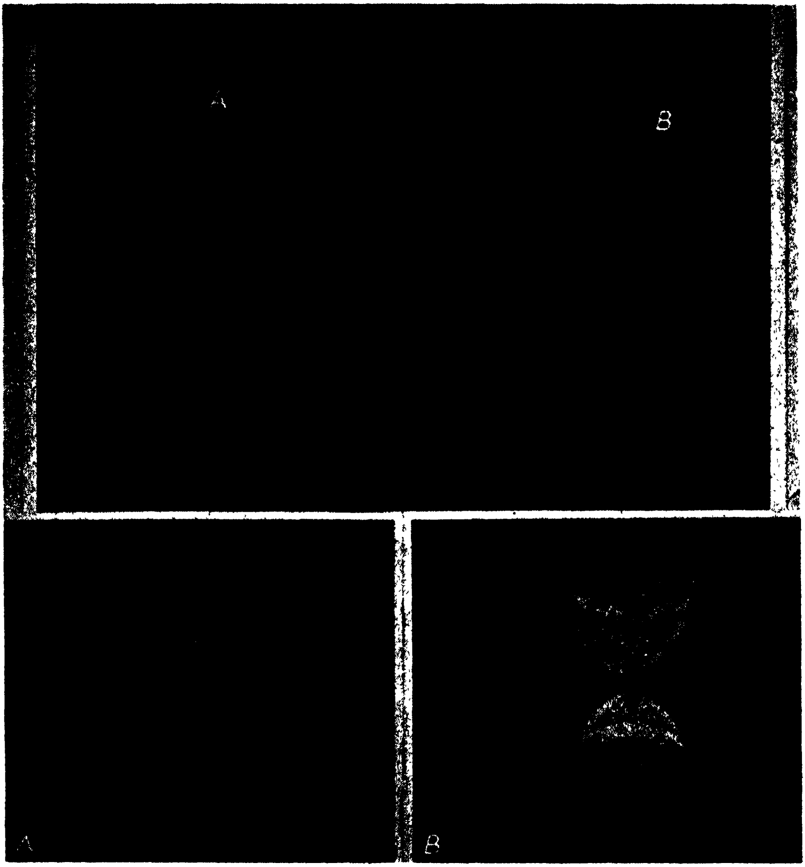


Fig. 15.8.1″—60° Double Vee Weld (at " A " Back of first side chipped out before welding second side, this chipping operation omitted at " B "). Slag inclusions at " A ", slag inclusions and bad lack of penetration at " B ": *Above*: X-ray Photograph indicating respective sections.

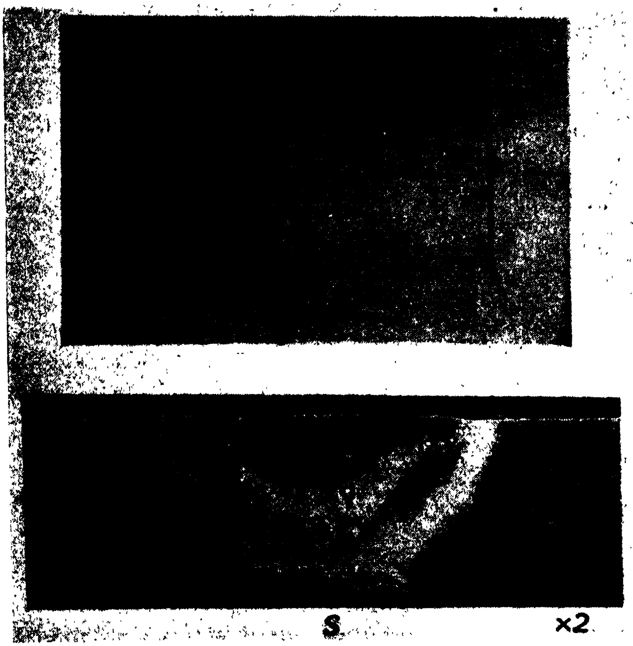


Fig. 15.9. ½″—60° Single Vee Weld with slight slag inclusion. *Above*: X-ray Photograph, black line indicating the section shown below.

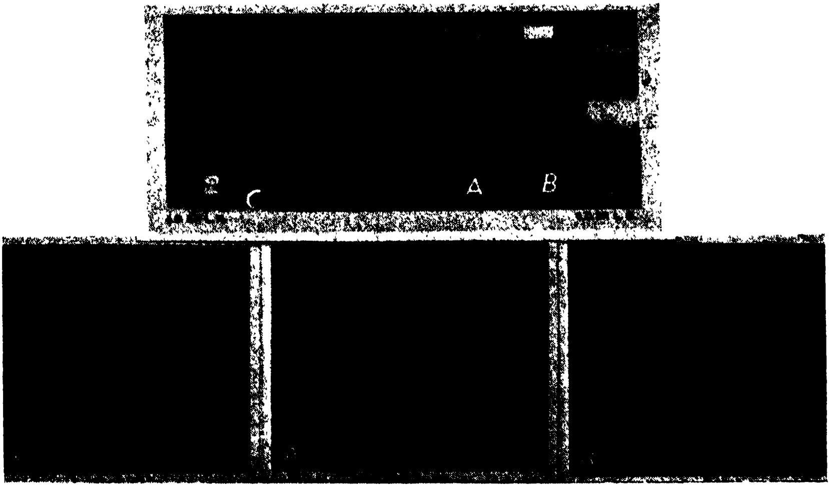


Fig. 15.10. 1″—20° U-weld as used in Pressure Vessels, produced with too low welding current. Light and heavy slag inclusions in slag traps.

Spot-welded test pieces, when pulled in the tensile testing machine, will always be only partly stressed in shear due to the tensile components created by the eccentric loading (Fig. 15.11) of the weld, and in a destructive test of a single spot weld tearing of the weld should be the cause of failure.[1]

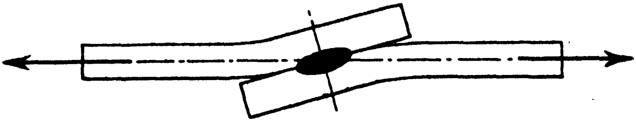


Fig. 15.11

In resistance welding, weld faults are usually caused through unsatisfactory preparation of the components, bad condition of the plant and equipment, and incorrect procedure, such as unsuitable electrode size, and faulty machine setting.

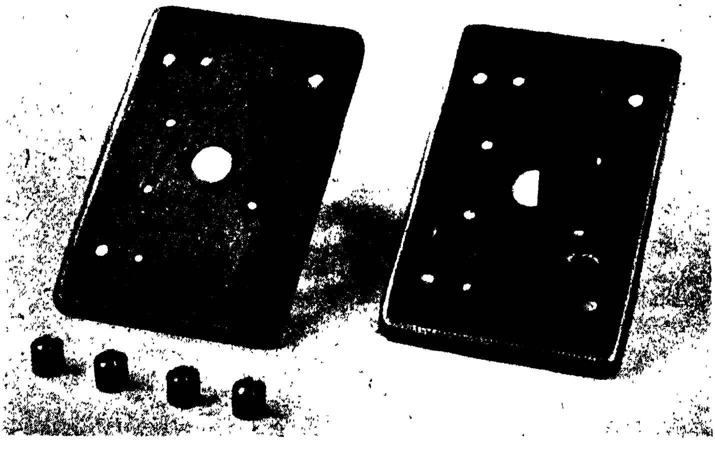


Fig. 15.12. Projection Welded component; two welds tested and proving satisfactory (*Metropolitan-Vickers*)

Good resistance welds should show good penetration to such an extent that fracture during a destructive test does not occur at the contact faces which have been welded. In the case of spot welds a slug of the diameter of the weld should be pulled out of one plate, and in the case of projection welds a similar lump of metal should be torn out of the plate (Fig. 15.12).

---

[1] See A. J. Hipperson, "Spot Welded Joints: A Survey of Available Mechanical Tests," *Welding*, October 1945.

Lack of cleanness on the surfaces to be welded will cause bad contact conditions and consequently poor welds. It may also be the cause for foreign matter inclusions and blow holes, thus reducing the weld strength. Pickling or shot blasting of the material prior to resistance welding will produce the required surface cleanness.

Although already previously mentioned (see page 77) the necessary precautions may be repeated, because of their great importance for the quality of spot and projection welds. Material up to $\frac{3}{16}$" thickness can be purchased in a pickled condition and slightly oiled for protection against corrosion. If the oil is clean there is no need to remove the oil film prior to welding, as it will be pushed away under the electrode pressure.

Thicker material should be shot-blasted before welding. Sand blasting is not recommended, as particles of the siliceous material may influence the electrical resistance at the joint surfaces, when they become imbedded in the material.

In the case of bad fitting between component parts, existing gaps have to be closed by bending the plates in question into their correct position. If this has to be done by the welding electrodes, the amount of electrode pressure used is lost to the actual forging process, and weak welds may result.

Unsuitable welding conditions can be caused not only by badly kept welding machine controls (see page 225) but also if the electrode shape (mushrooming, see page 79) is not kept at the required standard. Incorrect electrode-tip diameters may be the cause of unsuitable current and pressure density, causing indentation in the case of too small tip diameters, particularly if current or pressures are on the high side, or cracks in the case of too large tip diameters.

Lack of heat due to too low current and/or time settings causes lack of penetration, whilst too high settings may cause excessive penetration and overheated welds.

The maintenance of the plant (see page 225), care on the part of the setter up, and, usually, destructive tests at regular intervals will prevent serious difficulties.

Among non-destructive tests mention may be made of X-ray inspection, and testing of the change in magnetic permeability of the spots in stainless steel.[1]

---

[1] See "Testing Spot Welds: Non-destructive Method for Stainless Steels," *The Electrician*, July 25th, 1947.

CHAPTER XVI

DESIGN PRINCIPLES AND DRAWING OFFICE PROCEDURE IN CONNECTION WITH WELDING

To MAKE manufacture by welding a success, the welding shop must be capable of effectively putting into practice the three essentials; production planning, manufacturing procedure, and inspection.

The co-ordination of these three jobs should be in the hands of an experienced engineer who combines the faculties of a production manager with those of a welding expert.

Efficiency in the manufacture of welded components depends to a great extent upon the procedure used for executing the welds, and upon the correct preparation of the component plates and other parts of the welded structure. All these points must, therefore, be carefully planned, supervised and inspected.

The basic instructions on which planning department, shop supervision and inspection department are working, have to be issued by the technical department, the designs drawing office.

It is a fundamental error to issue only vague information in drawings from the designs office to the workshop and then leave to the operator the decision as to how to carry out the work. On the careful preparation and execution of the drawings depends to a large extent the success of the production in the welding shop.

Apart from the stress calculations and the design of various shapes, the drawing office has to provide the welding shop with the following information:

1. Cutting of plates and other component parts and the necessary weld preparations. 2. Size and type of welds. 3. Welding procedure and sequence (see pages 57 and 230). This has to be done in collaboration with the planning department. 4. Heat treatment specification, if heat treatment is required (see page 235). 5. Inspection instructions if any special conditions have to be observed.

With regard to the first point, the plate lay-out should determine the minimum amount of plate material required and the most economical way of cutting it. It should be remembered that guillotine operations are cheaper than flame-cutting or machining operations.

The often-used practice of leaving the lay-out of components on the plate material to the man in the shop, has several disadvantages. It is easier to try out the most economical cutting lay-out on paper in the drawing office, than to try it on steel plates in the shop. Furthermore the lay-out on the drawing represents a definite record which is kept in the D.O. Thus the whole work has only to be done once, and not every time the job is repeated in the works.

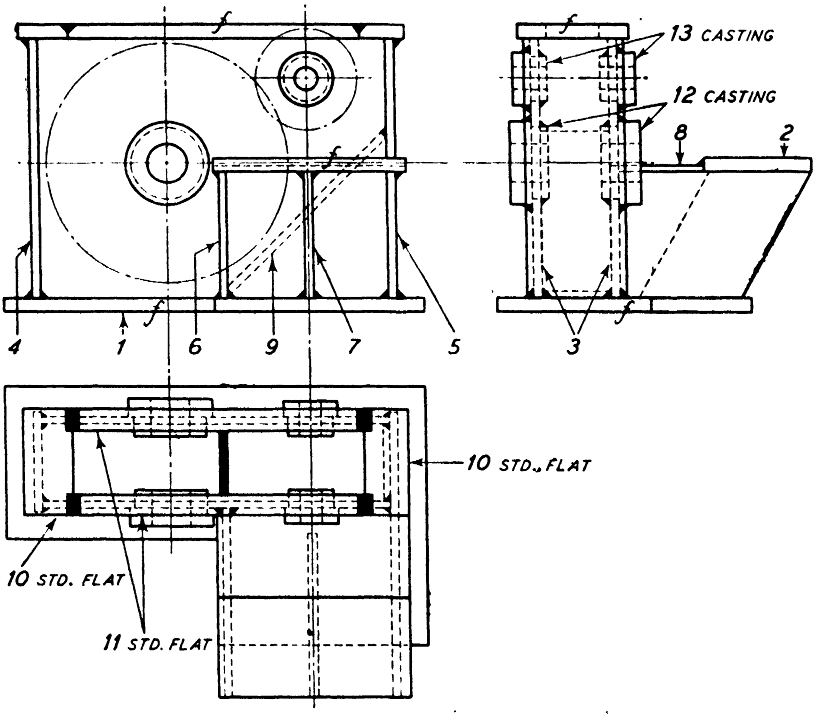


Fig. 16.1

For the example of a simple reduction gear box (Fig. 16.1),[1] the material-cutting drawing is shown in Fig. 16.2 which is self-explanatory. It is important to specify tolerances for plate preparation, as inaccurate plate preparation may reduce the effective strength of welds. For the example of a fillet weld connecting two plates at right-angles (Fig. 16.3) it will be found that, in order to obtain the required throat thickness of the weld, it is necessary to increase the amount of weld metal considerably if the gap between the two plates is excessive.

[1] From F. Koenigsberger, "The application of fabricated construction to machine design," *Proceedings of the Institution of Mechanical Engineers*, **152** (1945), page 245

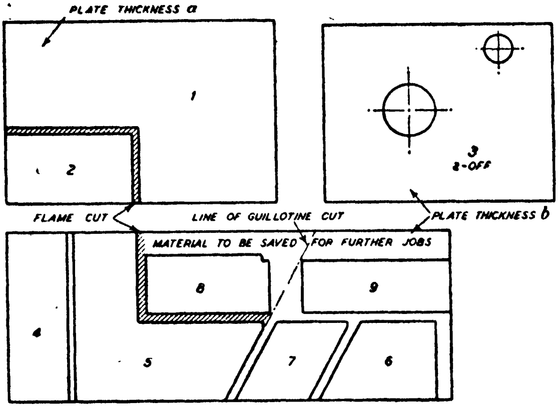


Fig. 16.2

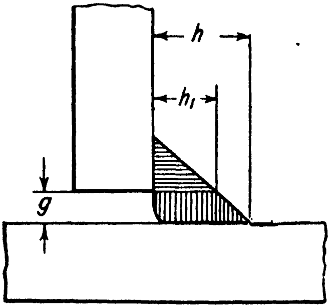


Fig. 16.3

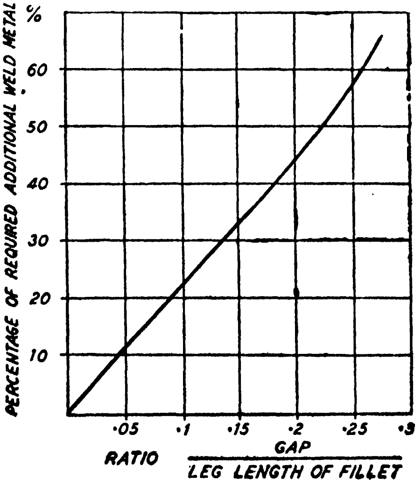
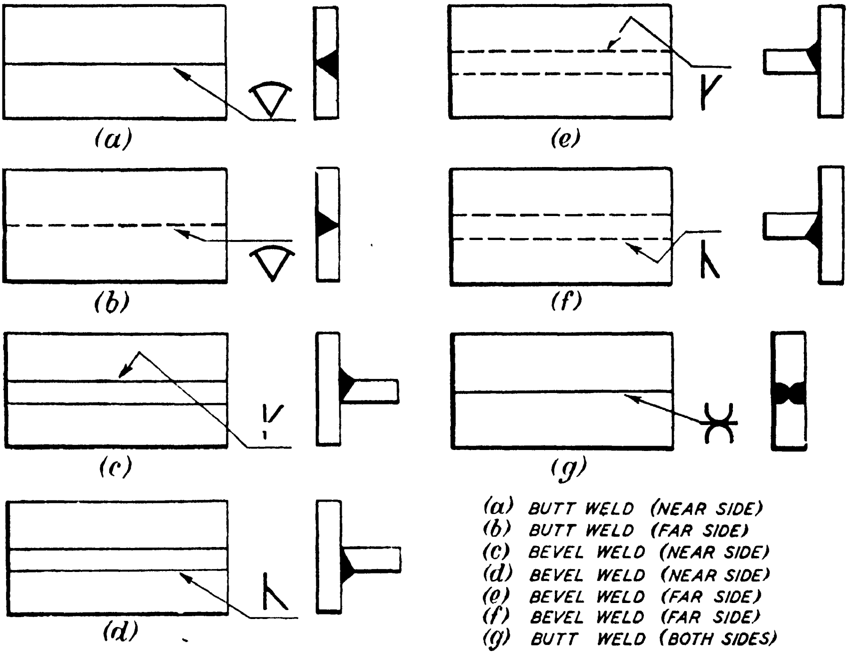


Fig. 16.4

Fig. 16.4 shows the relation between the additional percentage of weld metal and the ratio between the gap size and fillet size.

The weld sizes are determined by the permissible stresses in the weld.

Stress calculations of butt and fillet welds have been worked out for various types of welded joints.[1]


(a)
(e)
(b)
(f)
(c)
(g)
(d)
(a) BUTT WELD (NEAR SIDE)
(b) BUTT WELD (FAR SIDE)
(c) BEVEL WELD (NEAR SIDE)
(d) BEVEL WELD (NEAR SIDE)
(e) BEVEL WELD (FAR SIDE)
(f) BEVEL WELD (FAR SIDE)
(g) BUTT WELD (BOTH SIDES)

BUTT WELDS

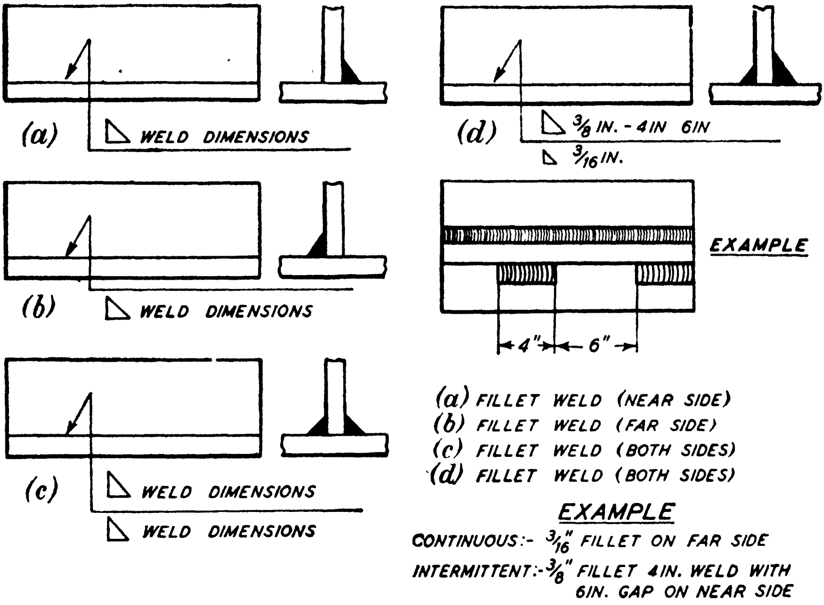
Fig. 16.5

Maximum permissible stresses for fusion welds in mild steel under static loads are specified in B.S.S. 538 (see page 238).

In order to simplify the specification of welds on drawings various systems have been suggested, and it is to be hoped that a standardized system such as the one shown in Figs. 16.5, 16.6[2] will soon be accepted and employed by the welding industry.

[1] See F. Koenigsberger, *Design for Welding* (Longmans, Green & Co., London, 1948).

[2] B.S.S. 499.


(a) WELD DIMENSIONS
(b) WELD DIMENSIONS
(c) WELD DIMENSIONS
WELD DIMENSIONS
(d) 3/8 IN. - 4 IN 6 IN
3/16 IN.
EXAMPLE
4"
6"
(a) FILLET WELD (NEAR SIDE)
(b) FILLET WELD (FAR SIDE)
(c) FILLET WELD (BOTH SIDES)
(d) FILLET WELD (BOTH SIDES)
EXAMPLE
CONTINUOUS:- 3/16" FILLET ON FAR SIDE
INTERMITTENT:- 3/8" FILLET 4 IN. WELD WITH 6 IN. GAP ON NEAR SIDE

FILLET WELDS

Fig. 16.6

For inspecting welds, gauges should be used. As an example the simple gauge (Fig. 16.7) checks the limits of fillet welds as specified in B.S.S. 538.

The calculation of spot welds is similar to that of rivets. They are calculated in shear, the weld diameter being assumed to equal the diameter of the electrode tip diameter (see page 77). The permissible shear stress for spot welds is 5 tons per square inch.

For dynamic and alternating loads on welds no figures for permissible stresses have been established yet, but the American Welding Research Council of the Engineering Foundation has established so-called "dependable" ultimate stresses of welds under fatigue loads (see page 239).

The instructions with regard to welding procedure should contain

(*a*) in the case of *arc welding* (see page 60): Number of welding runs for each weld; Type and size of electrodes to be used for each run and length of run per electrode; Amperage to be applied for each run.

(*b*) in the case of *resistance welding* (see page 87): Type and

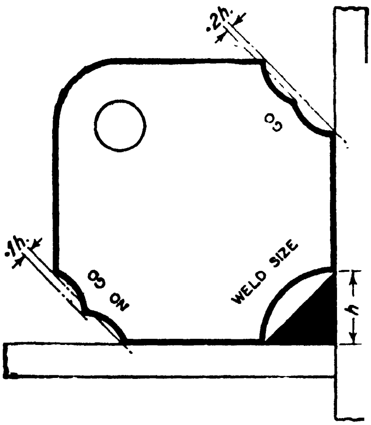


Fig. 16.7

size of electrode tip (spot welding); Specification of projection (projection welding); Pressure; Amperage; Time.

Recommended procedures for the stress-relieving heat treatment of welded structures have been described on page 235.

If high accuracy or stiffness against distortion under load are not required in a structure, the tensile strength of steel can be exploited to its full extent, and considerable savings can be made in the amount of material used. Such cases occur in the construction of bedplates, supporting structures, crane bridges, and even in certain machine tools, e.g. closed press frames.

For such structures the use of high tensile steels may sometimes be justified, although the special precautions necessitated by the weldability of such materials must be taken into account. In this connection it may be stated that there is no advantage in using high tensile steel instead of mild steel in cases where accuracy and stiffness against distortion are of first importance, because the modulus of elasticity determines the magnitude of distortions under load, and the modulus of elasticity of high tensile steel is practically equal to that of mild steel within ±3 per cent (30,000,000 lb. per square inch).

Bedplates serve to locate machines and machine groups in relation to each other and differ in overall size, shape, position of locating faces, etc., for each combination. Unless large numbers of plates of a given type are called for, fabrication is a very economical method of construction because patterns are not required.

Bedplates must be able to support the dead weight of the machines in question, and must also carry the working stresses created by the transmission of load between the machines fastened to them. Fig. 16.8 shows a fabricated bedplate for a motor compressor unit. The main structure is bent from one plate and welded only at the corners. Only four welds, each of a length equal to the height of the bedplate, are required. This design shows the practical application of the principle of reducing the amount of welding to a minimum, which has been achieved in this case by bending one plate to the required shape instead of welding two or more plates together at right angles.

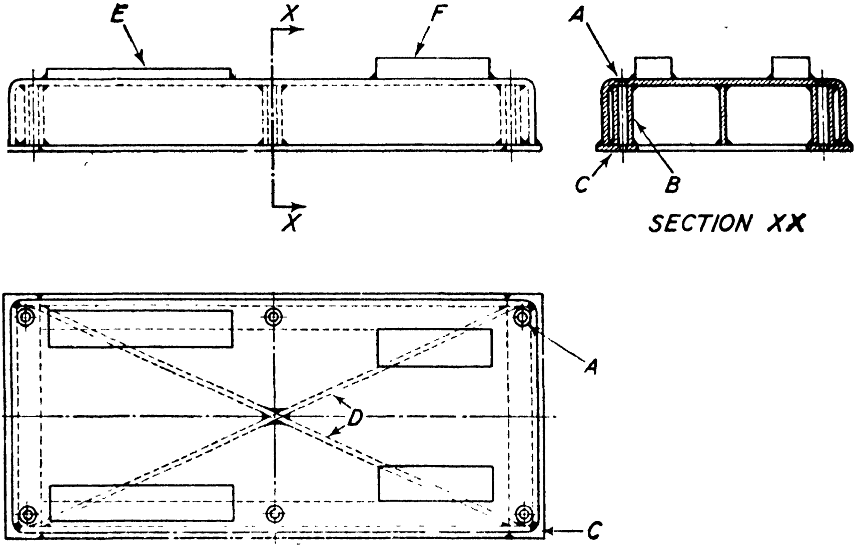


Fig. 16.8. Bedplate for motor-compressor unit

Although the external appearance of such a bedplate is similar to that of a casting, some differences will be noticed. Instead of using bosses with facings for the foundation-bolt nuts and washers, the top plate is spot-faced at " A " and the stress exerted by the foundation bolts is resisted by the tubes " B ". A frame " C " built of flats carries a structure which is strengthened against torsional stresses by diagonal ribs " D ". Machining pads " E " and " F " are provided. They have to be at different levels because the axes of motor and compressor are at different heights from their respective bases.

Whilst the previous bedplate is very similar in outside appearance to a cast iron one, certain savings can be obtained by departing from this similarity, e.g. by using standard rolled sections. The bedplates

(Fig. 16.9 and Fig. 16.10) show the application of standard sections, the main structure of the bedplate (Fig. 16.9) being formed of channels and that of bedplate (Fig. 16.10) by joists.

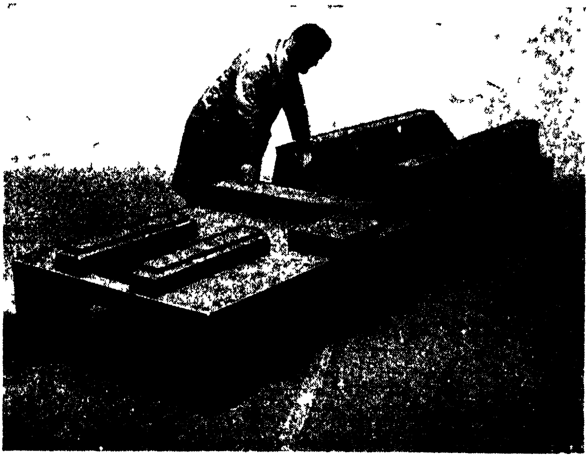


Fig 16.9 (*Cooke and Ferguson*)

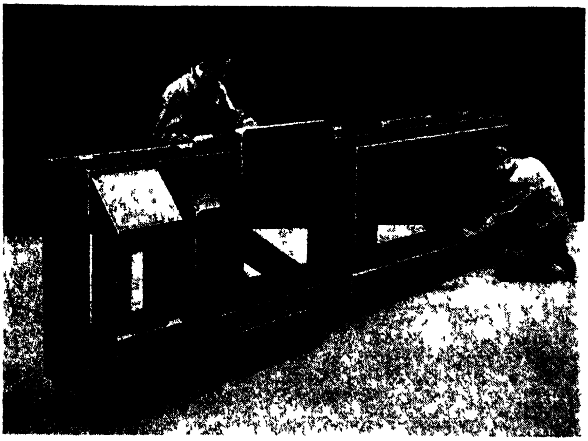


Fig. 16.10 (*Cooke and Ferguson*)

The advantage of the welded construction becomes particularly obvious when the structure in question is of very large size and serves a special purpose such that only one off will ever be required. In the case of casting one off only, the cost of the pattern may be the main item of the manufacturing cost.

The crane bridge (Fig. 16.11) is a welded structure which proves the statement made on page 2 that savings in weight can be obtained in an arc-welded structure as compared with a riveted structure. Whilst the principle and arrangement of the plates and rolled sections are identical with those used in riveted crane bridges, the size of the rolled sections can be reduced, because the full area and moment of inertia of the sections can be exploited without the necessity of allowing for any reduction due to rivet holes.

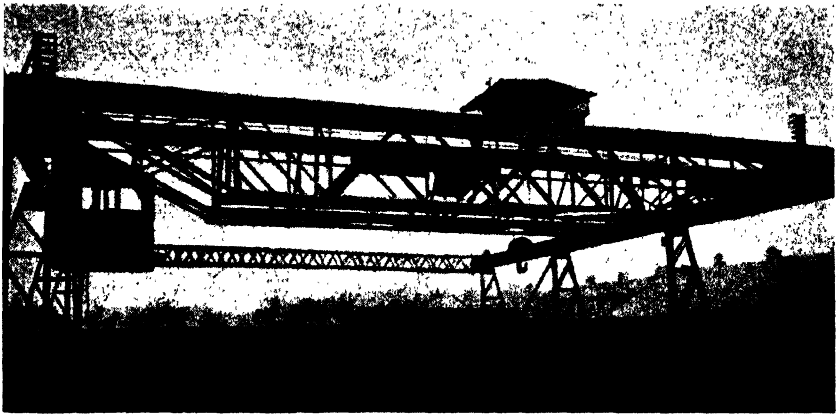


Fig. 16.11 (*Cooke and Ferguson*)

As a result, the total weight of the bridge was 11 tons, whilst the weight of the usual riveted crane bridge for a 58-ft. span and for a similar loading capacity (10 tons) would have been about 16 tons.

In the case of press frames, it is essential that the parallelism of ram and table be maintained. Pure elongation of the frame, however, may not be detrimental as long as the aforementioned condition is fulfilled. This applies for the case of closed frame presses where, therefore, the tensile strength of the steel can be fully exploited. The designer of the press frame (Fig. 16.12) has cut the main walls (front and rear) out of one plate each, thus causing the steel plates to take all stresses and using the welds for connecting and locating purposes only. This is not due to lack of confidence in the strength of the welds, but to the fact that welds which would be strong enough to carry the same load as the heavy frame plate sections would have to be built up by a great number of runs and would be uneconomical to manufacture.

The safe functioning of many machines might be jeopardized if the working accuracy obtained in manufacture is not maintained during

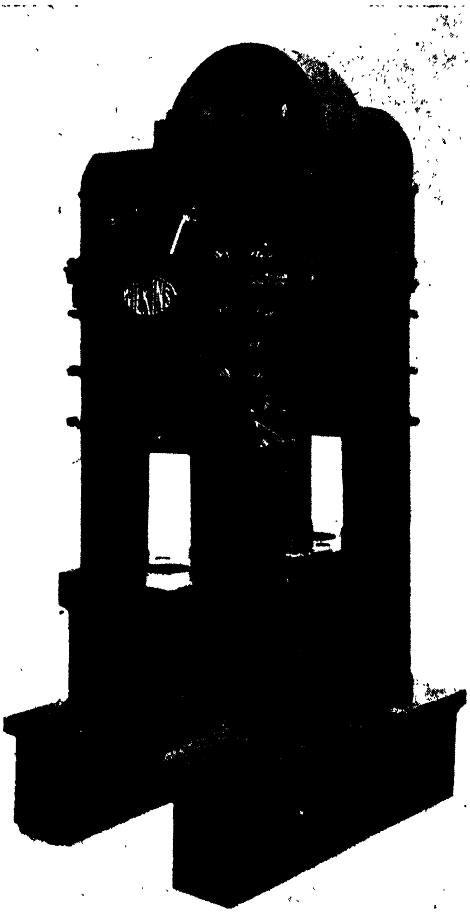


Fig. 16.12. Power Press *(Wilkins and Mitchell)*

the working life of the structure. This applies to machine structures such as those which support high speed shafts, gearing, and similar machine elements. The following points must be observed in design and manufacture of such structures:

1. Strength and stiffness to withstand the stresses and distorting forces acting under working conditions of the machine.

2. Strength and stiffness to withstand the cutting and clamping forces exerted during the machining processes throughout manufacture.

3. Accuracy in fabrication of parts which give alignment to important components (bearing bosses, locating faces, etc.).

4. Stability, i.e. elimination of residual stresses which might cause creeping of the structure during its working life.

The two fundamental principles which a designer has to observe are simplicity of design and the automatic location of components in the correct position.

With regard to strength and stiffness, the designer must obtain high moments of inertia and strong sections which withstand the loads exerted on the structure.

In the case of U-shaped openings there is a danger of the two sides closing in towards each other during the welding operation (see page 228), and it is necessary to provide stiffeners which keep the two sides in position. The selection of the size of such stiffeners should under no circumstances be left to the operator in the welding shop, but should be determined by the technical department, i.e. the designs drawing office. It may not be possible to calculate theoretically the exact magnitude of the distorting forces. They can, however, be determined experimentally on the prototype or developing model, and the experience thus gained should be recorded by the drawing office and then transmitted to the shop for future production.

The magnitude of the distorting forces created by the welding heat should not be under-estimated and should be considered when working out the stresses in various parts of the structure.

The prevention of distortion by means of stiffeners will create internal stresses (see page 233) which have to be eliminated prior to removing the stiffeners. The stiffeners have to be left in the structure during the stress-relieving heat treatment. They must be knocked out mechanically (not by means of flame cutting which might introduce new stresses) after heat treatment.

After correct stress-relieving heat treatment the structure does not close in when the stiffeners are removed. Elimination of residual stresses will also prevent excessive creeping of the structure during its working life. The permissible amount of eventual creeping will determine the specification of the stress-relieving heat treatment (see page 235).

High precision machine tool structures, and machining jigs and fixtures have to be designed and built in such a way as to give accurate alignment and guidance to the tool and to the component in every position of their various movements, within specified limits, and to maintain these accuracies when the structure is under working load and during the working life of the machine.

It is an old prejudice amongst machine tool designers and users that a machine body has to be heavy, in order to be rigid and free from vibrations.[1]

In the case of grinding and milling machines the danger of vibrations is particularly great because of the pulsating cutting conditions and the high speeds which are likely to be used. The body of the "Discus" surface-grinding machine has been built of $\frac{5}{32}''$ plates. Rigidity is obtained by the so-called "cell" construction which has been patented (Fig. 16.13). Spot welding has been used in parallel with arc welding in the construction of this machine and of similar other machines of the same manufacture.

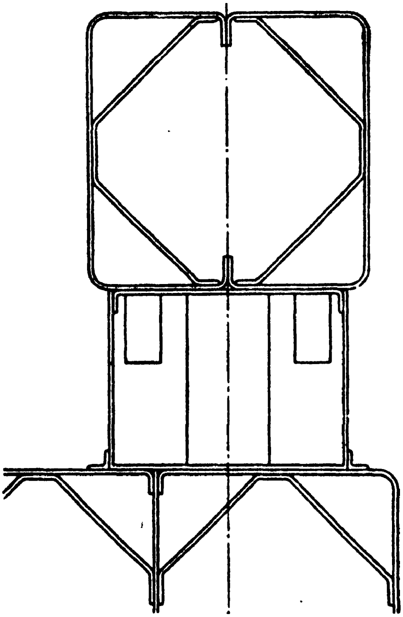


Fig. 16.13

The fabricated production milling machine (Fig. 16.14) has a spindle-speed range from 20 to 1700 r.p.m. As an example of the simplicity which is fundamental for the design of fabricated precision structures, a section through the main upright (Fig. 16.15) shows how the amount of welding is reduced by folding and bending operations. The use of cast iron slides which are bolted on to the main structure has proved to be the most economical method of manufacture in this particular case, whilst the slideways for the saddle are of 0·4 per cent carbon steel and are flame-hardened and ground.

---

[1] See F. Koenigsberger, "Must a Rigid Machine Tool be Heavy? ", *Machinery*, April 18th, 1940; and "The Application of Fabricated Construction to Machine Design," *Proceedings of the Institution of Mechanical Engineers*, 1945, Vol. 152, page 245.

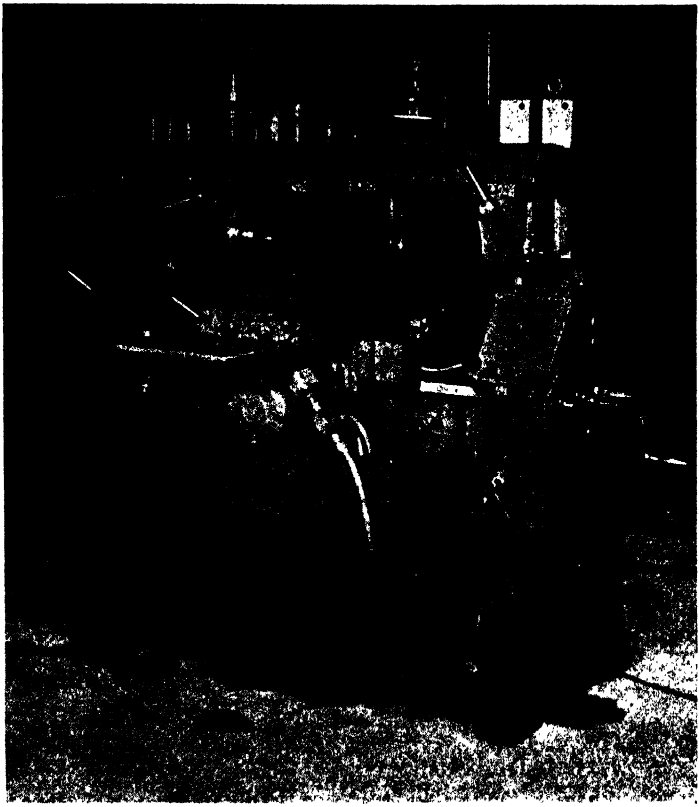


Fig. 16.14. Production Milling Machine (*Cooke and Ferguson*)

Based on experiments with the above-mentioned general-purpose production machine, the special-purpose light alloy duplex milling machine (Fig. 16.16) has been developed, which, at a maximum spindle speed of 1700 r.p.m. and a maximum cutter diameter of 24″, gives a maximum cutting speed of 10,000 feet per minute.

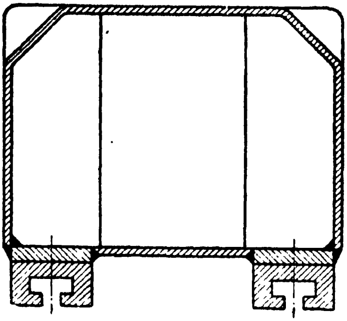
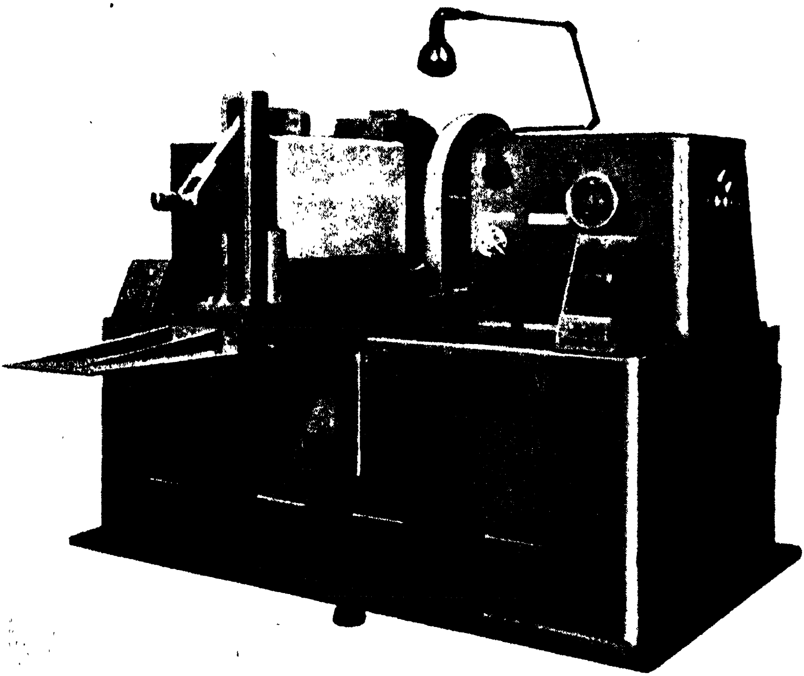


Fig. 16.15



(*Cooke and Ferguson*)

Fig. 16.16. Special Purpose Light Alloy Duplex Milling Machine

Only one off this latter machine was required, and the advantage of eliminating the need for patterns will be particularly obvious in this case. The simplicity of the structure has made possible the completion of the machine in a minimum amount of time. Vibration measurements and surface examination of the components which were machined on the two milling machines (Figs. 16.14 and 16.16) have proved that the fabricated structure gives results equivalent to those obtained on cast iron machines. The saving in weight was about 30 per cent as compared with cast iron construction.

CHAPTER XVII

SOME NOTES ON ESTIMATING FOR MANUFACTURE BY WELDING

TECHNICAL or economic considerations, or both, will determine which welding process is the most desirable in connection with any specific job.[1]

With regard to *fusion welding processes* it is generally considered that the oxy-acetylene welding of steel is limited to small thicknesses, whilst it may be used for welding nearly any thickness of cast iron and and many non-ferrous metals. Arc welding, with its higher welding speeds, is increasingly favourable economically and creates less distortion as the thickness of the steel plate increases; and other fusion welding processes have their specialized applications (see pages 4 and 6). The graph (Fig. 17.1)[2] shows a comparison of welding speeds

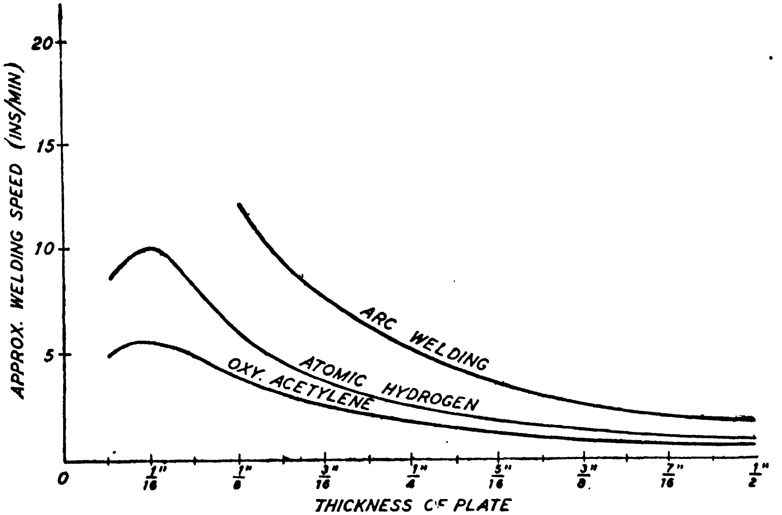


Fig. 17.1

---

[1] See H. St. G. Gardner, "System of Indicating Welding Requirements on Engineering Drawings," *Transactions of the Institute of Welding,* February 1945, p. 38.

[2] From I. H. Hogg, "Atomic Hydrogen Welding," *Metropolitan-Vickers Gazette,* October 1945, p. 117, by kind permission of Metropolitan-Vickers Electrical Co. Ltd., Manchester.

obtained with the oxy-acetylene, atomic hydrogen, and metal-arc welding processes. The outstanding feature of the *resistance welding* processes is the speed with which the joints may be produced once the welding machines have been set correctly. Unskilled labour may be employed if modern equipment which automatically controls all factors (current, pressure, and timing) influencing the weld, is available.

Apart from the actual welding speeds, other factors have to be considered in estimating the cost of manufacture by welding. Many materials necessitate particular precautions, e.g. alloy steels may require special electrodes, preheating or postheating of the work, etc. (see page 107). Careful identification of the material in the stores is necessary to prevent cases in which mild steel is supposed to be used and alloy steel is issued by mistake. Failures in welds may be caused if the equipment used and the welding procedure applied are not suitable for the material under construction (see page 241). A simple colour scheme will often prove effective in identifying material as received from suppliers, though it may be advisable to test samples from time to time to determine whether the required specification has been maintained by them.

Careful supervision (see page 238) is essential in order to guarantee that the specified procedures are carried out by the operators or setters, and the staff required for checking and supervising all the above-mentioned points causes, of course, increased expenses in the welding shop. It will usually be found, however, that the money is well spent in view of the improved quality of work and the lesser need for repairs and rectifications.

For estimating the manufacturing cost of welded components, material cost, labour cost and overhead expenses have to be considered.

A list of materials required (issued for each particular job by the drawing office) together with material-cutting drawings (plate lay-outs, see page 251) will usually form the best basis for estimating the cost of the first item. To this should be added the cost of electrode or filler rod material which has to be estimated from the size and length of welded seams in the structure, allowing up to 3 inches per electrode for unused ends.

The overhead expenses will vary, according to the plant and organization of the factory, between 100 and 150 per cent of the labour cost involved.

The method of calculating both the above items does not differ greatly from that used when estimating the cost of other manufacturing processes.

The labour cost involved in plate preparation, flame cutting, assembly and welding, needs special consideration. The savings which are possible through suitable design should be carefully considered. Mention may be made of bending one plate rather than welding two plates at right angles to each other, and the use of compound construction by using steel castings or drop forgings for complicated portions of a structure. The higher speed of guillotine cutting as compared with that of flame cutting[1] should not be overlooked when drawing the lay-out of details on the plate material drawing (see Fig. 16.2). To the saving in deposited weld metal and, consequently, welding time, in case of more accurate plate edge fitting (see Fig. 16.3) must be added the fact that, due to the lower heat input when filling smaller gaps, less stretching of possible distortions is required.

All these points, together with the economy obtainable by using efficient plant, such as high-powered welding machines, manipulators, or by providing cutting templates and assembly fixtures for quantity production, have a bearing on the time spent by platers, fitters, and welders in preparing and completing their job.

The actual flame-cutting and welding times and the labour cost spent on this work depend then only upon the ease of setting the machines, and upon the obtainable cutting and welding speeds.

Typical flame-cutting speeds obtainable with modern plant have been shown on Table 32 (see page 189).

The actual welding times have to be made up from the speed in setting the welding currents, laying down the weld metal (plus time for chipping off slag) and, in the case of metal-arc welding, changing electrodes.

Positioning of the work, with or without manipulator or special fixtures, will also have considerable influence upon the effective welding speed, i.e. the floor-to-floor time in the welding assembly shop. These "handling" times are best found by careful rate-fixing, as they vary with the available plant, type and size of the work concerned, and general conditions of the shop. Once established, they can, of course, be tabulated and serve for general estimating purposes in the shop concerned. Typical net welding speeds of depositing weld metal in mild steel are shown in Table 37 for the case of butt welding (simple V-preparation) by the oxy-acetylene welding process, and in Tables 38 to 42 for the case of metal-arc welding.

---

[1] See J. A. Dorrat, " Economics of Arc Welding: The Relationship of Production and Costs," *Welding*, January 1947.

TABLE 37

Approximate estimate of time taken, per foot length of Mild Steel Butt Weld by the Oxy-Acetylene Process (single V-preparation)[1]

Thickness of plate (inches)	Filler rod diameter (inches)	Welding time per foot length of weld (mins.)
1/16	1/16	2·5
1/8	3/32	3·0
3/16	1/8	4·5
1/4	1/8	5·5
5/16	5/32	8·0
3/8	3/16	9·5

British Oxygen Co., Ltd.

TABLE 38

Approximate Estimate of Time Taken Per Foot Length of Mild Steel Butt Weld by the Metal-Arc Process (single V-preparation)[1]

Plate thickness	Number of runs	Welding time, including time for sealing run, chipping off slag and changing electrodes
inches		mins.
1/4	2	6
3/8	3	10
1/2	4	15
5/8	5	23
3/4	6	27
1·	6	28

---

[1] Murex Welding Processes Ltd.

TABLE 39

Approximate Estimate of Time Taken Per Foot Length of Mild Steel Butt Weld by the Metal-Arc Process (double V-preparation)[1]

Plate thickness	Number of runs per side	Welding time, including time for chipping off slag and changing electrodes
inches		mins.
¾	3	19
⅞	3	20
1	4	23

Murex Welding Processes Ltd.

TABLE 40

Approximate Estimate of Time Taken Per Foot Length of Mild Steel Butt Weld by the Metal-Arc Process (unprepared, deep penetration electrodes)[1]

Plate thickness	Number of runs	Welding time
inches		mins.
¼	1 (with backing strip)	1·2
⅜	1 (with backing strip)	1·2
½	2 (one from either side)	2
⅝	2 (one from either side)	2

[1] Murex Welding Processes Ltd.

TABLE 41

Approximate Estimate of Time Taken Per Foot Length of Mild Steel Fillet Weld by the Metal-Arc Process (downhand welding)[1]

Size (leg length) of fillet	Number of runs	Welding time, including time for chipping off slag and changing electrodes
inches		mins.
$\frac{1}{4}$	1	2
$\frac{3}{8}$	2	5
$\frac{1}{2}$	3	6
$\frac{5}{8}$	3	8
$\frac{3}{4}$	3	11
1	6	24

[1] Murex Welding Processes Ltd.

TABLE 42

Approximate Estimate of Time Taken Per Foot Length of Mild Steel Fillet Weld by the Metal-Arc Process (overhead welding)[1]

Size (leg length) of fillet	Number of runs	Welding time, including time for chipping off slag and changing electrodes
inches		mins.
$\frac{1}{4}$	2	3
$\frac{3}{8}$	3	6
$\frac{1}{2}$	6	12

[1] Murex Welding Processes Ltd.

These net times do not include the previously mentioned handling times, and the actual time of completing a certain footage of welded seam will be longer than the net welding time shown in the tables. It may, however, be possible to establish for a particular welding shop a kind of empirical efficiency factor with which the times in the above table could be multiplied in order to obtain the total floor-to-floor time of the welding operations.

In the case of resistance welding, the actual welding times are usually so short that the "handling" times, such as putting the components into the fixture, or directly on the machine, and taking the completed assembly out, will generally be the deciding factor. Such times will have to be found by time study or similar methods.

APPENDIX

Some Means of Identifying Metals to be Welded

MATERIAL		*Surface Appearance*	*Magnet Test*	*Spark Test (Grinding)*	*Lathe Chip Test*	*Blowpipe Test*
CLASS	TYPE					
FERROUS	**Low Carbon Steel**	Dark Grey, may be rusty	Magnetic	Light sparks ending in small bursts or forks	Long, often continuous chips	Fast melting, quiet slag, puddle sparks
	High Carbon Steel			Duller in colour, small complicated bursts		
	Stainless Steel (18–8 or 25–12)	Dark Grey dull to brilliant, usually " clean "	Non-Magnetic	Bright Yellow sparks, no bursts		Fast melting, puddle livelier but less sparking than steel, and glistening
	Grey Cast Iron	Dull Grey, evidence of sand mould	Magnetic	Dull Red sparks, complicated bursts	Short (½") chips	Moderate melting speed, quiet slag, quiet puddle
NON-FERROUS	**Nickel**	Dark Grey, smooth, sometimes Green (Oxide)	Magnetic		Cuts easily, smooth edges, chips can be continuous	Melts slower than steel, less slag than monel, quiet puddle
	Monel	Dark Grey, smooth	Slightly magnetic at room temperature	Short faint Red sparks, no bursts		Melts slower than steel, considerable quiet slag, quiet puddle
	Brass	Yellow to Green, or Brown	Non-Magnetic		Smooth long chips, more brittle than copper	Moderate melting speed, gives off fumes, puddle like water
	Tin Bronze	Red to Brown				Fast melting, some fumes, puddle like water
	Copper	Smooth, Red-Brown to Green (Oxides)			Smooth long, easily cut chips	Slow melting, very little slag, puddle bubbles
	Aluminium	Light Grey to White, dull or brilliant			Smooth chips, saw edges where cut, chips can be continuous	Very fast melting quiet dark scum forms, quiet pasty puddle
	Magnesium Alloy	White, surface coating may be Yellow-Brown			Short, easily cut chips	

See J. E. GARSIDE, *Metallic Materials Inspection with Particular Reference to Non-Destructive Testing Methods.* Transactions of the Manchester Association of Engineers, Session 1945/46, page 89

AUTHOR INDEX

Aborn, R. H., 105
Allison, H., 234
Andrews, W., 103
Ashcraft, D. J., 127

Benson, L. E., 234
Berriman, A. E., 233
Blair, J. S., 94
Boyd, G. M., 198
Burton, C. A., 163, 164, 225, 226

Cameron, T. B., 127
Childs, W. J., 109
Cottrell, A. H., 107
Crowther, P. D., 107

Davies, E., 118
Dearden, J., 106
Della Vedowa, R., 125
Dever, F. S., 240
Dorrat, J. A., 267
Doty, A. W. D., 109
Drucker, R., 209

Erker, A., 237

Flanigan, A. E., 103
Fuchs, E., 244

Gardner, H. St. G., 107, 265
Graf, O., 198
Greene, T. W., 235, 236

Hanson, D., 107
Harding, E. W., 224
Hartbower, C. E., 103
Hatfield, Dr. W. H., 1
Hess, W. F., 125, 127
Hill, V. J. D., 124
Hipperson, A. J., 214, 248
Hogg, I. H., 6, 69, 70, 120, 122, 265
Holzbaur, A. A., 235, 236

Jackson, C. E., 103
Johnston, D. B., 95

Kerr, D. M., 27
Knipe, W. A., 98, 99
Koenigsberger, F., 251, 253, 261

Langmuir, 6
Lunn, D. C. F., 124
Luther, G. G., 103

Mannox, F. C., 73
Mullins, L., 244

Nippes, E. F., 125

O'Neill, H., 105, 106
Orr, J., 234

Pearce, J. G., 112
Pemberton, H. N., 243
Pocock, P. L., 32, 33

Reeve, L., 103, 107
Reynolds, E. A., 125
Richardson, G., 111
Riddihough, M., 115
Rohrig, I. A., 109
Ronay, B., 105
Rosenberg, 153

Semper, E. S., 185, 186, 197, 200, 232, 233
Silverwood, B. W., 27
Smith, S. H., 244
Stitt, J. R., 234
Stringham, L. K., 109

Thompson, R. N., 200
Tylecote, R. F., 125
Thum, A., 237

Van der Willigen, P. C., 43

Waller, W. D., 40
Warner, W. L., 103
Watson, T., 214
Wheeler, J. A., 107
Williams, R. D., 76
Winsor, F. J., 127
Winterton, K., 107
Wyant, R. A., 127

Zambrow, J. L., 76

SUBJECT INDEX

A.C. welding, 28
— — multi operator equipment, 32, 157
— — power factor, 29, 155
— — transformer, 30, 155
— — — current adjustment for arc welding, 155, 156
— — — temperature rise, 156
— — — for three phase supply, 31, 157
Acetone (dissolving acetylene), 136
Acetylene, 130
— consumption, 138
— cylinders, 136
— dissolved, 136
— feather, 25
— generators, 130
— — maintenance, 223
Alignment clamp, 229
Aluminium, 120
— cleaning before and after welding, 121
Aluminium alloys, 120
— — atomic hydrogen welding, 121
— — cleaning before and after welding, 121, 124
— — flash butt welding, 125
— — metal-arc welding, 122
— — oxy-acetylene welding, 122
— — projection welding, 125
— — seam welding, 125
— — spot welding, 124
Ammonia cracker, 68, 161
— — economy of application, 69
— cylinder, 161
Angle between electrode and plate, 243
Aprons, 220
Arc, 25
— blow, 26
— characteristic, 26
— length, 26, 37
— striking voltage, 26
— stud welding, 64
— — — equipment, 157
— voltage, 26, 27, 146
Arc welding equipment, 27, 145
— — — earthing, 218
— — — maintenance, 224
— — generator, 29, 145
— — technique, 37
— — transformer, 30, 155
Argon-arc welding, 4, 34
— — equipment, 34
— — high frequency unit, 35
— — interchangeable torch heads, 36
— — magnesium alloys, 127
— — polarity, 36
— — stainless steel, 110
— — technique, 37
— — tungsten electrode, 36
— — welding torch, 36
Atomic hydrogen welding, 6, 67
— — — aluminium alloys, 121
— — — automatic, 71
— — — copper alloys, 120
— — — current settings (mild steel), 70
— — — electrical plant, 67
— — — equipment, 67, 160
— — — filler rods, 70
— — — hard facing, 116
— — — hydrogen plant, 68, 161
— — — loss of carbon, 70
— — — open circuit voltage, 67
— — — stainless steel, 110
— — — technique, 69
— — — torch, 69
— — — transformer, 160
Austenitic electrodes, 109
— structure, 104
Automatic metal-arc welding, 57

Back firing, 135, 143, 144, 186
Back pressure valve (hydraulic), 15, 134
— — — — maintenance, 223
Backing strip, 45, 119, 123
BEAMA classification of electrodes, 40
Bedplates, welded, 255
Bend test, butt welds, 244
— — fillet welds, 244
Blacksmith welding, 7
Blow holes, 103, 240, 243
— — in welds of tough pitch copper, 118
— — in welds of copper-zinc alloys, 120
Blowpipe, cutting, 187
— oxy-acetylene welding, 3
— — — high pressure, 13, 143
— — — low pressure, 13, 142
— — — maintenance, 223
Bronze welding, 114
— — cast iron, 114
— — dissimilar metals, 115

Bronze welding malleable iron, 114
— — preheating castings, 115
— — strength, 114
— — tough pitch copper, 118
B.S.S. 499: 253
— 538: 43, 44, 45, 237, 238, 253, 254
— 638: 27 156
— 639: 40
— 679: 222
— 807: 81
— 1140: 77, 81, 83
— 1295: 240, 244
Building up of welds, 43
Butt (resistance) welding, 3, 10
Butt (Thermit) welding, 73
Butt welds, 19, 47
— — bend test, 244
Buttering layer (cast iron), 114

Calcium carbide, 130
Capacity of manipulators, 206, 208, 210
Carbide-to-water generator, 131
Carbon content, 105, 117
— equivalent, 106
Carbon-arc welding, 4, 32
— — automatic, 33
— — cast iron, 113
— — copper alloys, 120
— — technique and equipment, 32
Carburizing flame, 16
Cast iron, 112
— — bronze welding, 114
— — buttering layer when filling large gaps, 114
— — carbon-arc welding, 113
— — edge preparation for welding, 113
— — flame cutting, 199
— — grey, 112
— — malleable, 112
— — metal-arc welding, 114
— — oxy-acetylene welding, 113
— — Thermit welding, 114
— — white, 112
Cast steel, 112
Cell construction, 261
Characteristic (arc), 26
— drooping, 28, 29
— dynamic, 147
— static, 147
— variable, 146, 148
— welding current supply plant, 146
Chilling to prevent distortion, 233
Classification of arc welding electrodes, 40
Cleaning acetylene generators before repair, 223
— blowpipe nozzles, 144, 223
Cleaning parent material before resistance welding, 77, 249
Coal gas for flamecutting, 186
Coated electrodes, 39
— — for stainless steel, 110
Condenser charge timing, 158, 173
Contact arc welding, 43
— system of acetylene generation, 133
Cooling spot welding electrodes, 79
— rate (weld metal), 104, 105, 107, 109
Copper alloys, 120
— de-oxidised, 118
— oxy-acetylene welding, 118
— tough pitch, 118
Corrosion, aluminium, 120
— by remaining flux, 121
— stainless steel after welding, 111
— stress, 234
Cracking, 46, 103, 104, 106, 107, 240
— after stelliting, 116
— in aluminium alloy welds, 122
— in Thermit welds of cast iron, 114
Crane bridge, welded, 258
Cross field generator, 153
Crucible for Thermit welding, 72
Current density flash butt welding, 94
— — projection welding, 93
— — spot welding, 77, 79, 88
Current settings in metal-arc welding, factors influencing them, 57
Cutting speed (flame cutting), 186, 189
Cyc-arc stud welding, 65, 157
Cylinders, 12
— acetylene, 136
— ammonia, 161
— argon, 34
— hydrogen, 68
— manifold arrangement, 139
— oxygen, 129

D.C. electric-arc welding, 28
— — — generators, 29, 145
— — — multi-operator, 30, 147
Deep-penetration welding, 40
— — procedure specification, 49, 51
Dependable stresses for welds, 238
Design principles, 250
Dissolved acetylene, 136
Distortion, 106, 212, 227
— of aluminium alloys, 121
Downhand welding, 46
— — procedure specification, 48–51, 53
Drawing office procedure, 250
Drooping characteristic of arc welding supply plant, 28, 29, 155
Drying of silicon aluminium electrodes, 123

Ductility, 104, 105, 106, 107, 109
— in welds of tough pitch copper, 118

Earthing arc welding plant, 218
— — — — checking, 224
Economizer (oxy-acetylene), 18
Edge, fatigue strength, 198
— flame cut, 186
— quality, 186, 189
Edge distance of spot welds, 89
Edge preparation, cast iron, 114
— — copper, 119
— — stainless steel, 110
— — steel, 22, 44, 45, 201
Effective length of weld, 237
Electric-arc welding, 4
— — processes, 25
Electrodes, allowance for cost, 266
— argon-arc welding, 36
— bare, 38
— classification, 40
— coated, 39
— metal-arc welding, 38
— nickel-alloy for welding cast iron, 114
— storage, 224
— for spot welding, 81
— — — cooling, 79
— — — mushrooming, 79
— — — pressure control, 83
— — — pressure gauge, 225
— — — tip diameter, 77
— — — trimming, 226
Electrode holders (metal-arc welding), 37
Electro-mechanical timer, 165
Electronic timing control, 87, 166
Embrittlement, 70, 103, 107
— in stainless steel welds, 110
Estimating, 265
Extinguishing oxy-acetylene flame, 18
Eye flash, 221
Eye protection, 220

Fatigue strength, flamecut edges, 198
— — internal stresses, 234
— — welds, 237, 238
Faults in welds, 237
Ferrolene, 186
Ferrous metals, 103
Filler rods for atomic hydrogen hard facing, 117
— — — cast iron, 113
— — — de-oxidized copper, 118
— — — oxy-acetylene welding, 24
— — — silicon-aluminium, 121
— — — stainless steel, 110
Fillet welds, 20, 47
— — bend test, 244
— — minimum sizes, 46
Fixtures, 205, 212
— for resistance welding, 214
Flame (oxy-acetylene), 16
— — carburizing, 16
— — extinguishing, 18
— — lighting, 18
— — neutral, 16
— — oxydizing, 16
— adjustment (oxy-acetylene welding), 16
— — for welding copper, 119
— — for welding copper-zinc alloys, 120
Flame cutting, 185
— — accuracy, 197
— — blowpipe, 187
— — cast iron, 189, 199
— — distortion, 232
— — heat effects on plate, 198
— — machines, 192
— — pipes, 194
— — preheating, 188, 189
— — profile, 188, 193
— — quality, 186, 189
— — settings, 189
— — speed, 189
— — stackcutting, 196
— — stainless steel, 200
— — templates, 193, 197
— — thin plates, 187
— — width of cut, 197
Flame gouging, 185, 201
— — technique, 203
Flash, through arc welding, 221
Flash butt welding, 10
— — — aluminium alloys, 125
— — — application, 94
— — — current densities, 94
— — — machines, 86, 99
Flux, 32, 41, 64, 65, 103
— application for bronze welding, 115
— — — flame cutting, 200
— — — welding cast iron, 113
— — — welding stainless steel, 110
— de-oxidising for aluminium, 121
— for atomic hydrogen welding aluminium alloys, 121
— for welding magnesium alloys, 127
— mixing for oxy-acetylene welding aluminium alloys, 122
— removal after welding aluminium, 121
— trapping by unsuitable weld design, 121
Forge welding processes, 76

Freezing of cylinder valves, 129
Fume extraction, 220

Gas-pressure (oxy-acetylene flame), 18
Generators (acetylene), 130
— — maintenance, 223
— (D.C.), 29, 145
— — maintenance, 224
Gloves, 220
Goggles, 220

Hard facing, 115
Heat treatment, 107, 234
— — of cast steel, 112
— — of stainless steel to prevent weld decay, 112
Helium-arc welding, 4
Helmets (arc welding), 221
High frequency unit for arc welding, 35
High pressure oxy-acetylene welding, 12
— — — — blowpipe, 13, 143
— — — — nozzle sizes for welding steel, 14
— — — — pressure settings for welding steel, 14
High tensile steels, 106, 107
— — — arc welding procedure, 109
— — — resistance weldings settings, 107
Home Office memorandum, 218
Horizontal–vertical position, 46
— — procedure specification, 54
Hydraulic back pressure valve, 134
— — — — maintenance, 223
Hydrogen cylinders, 68
— flame cutting, 186
— plant, 68, 161

Ignitron, 170
Indentation through spot welding, 77, 249
Inertia (electrical) of arc welding supply plant, 145, 151
Injector nozzle (injector), 142
Injector-type blowpipe, 3, 144
Inspection, 244, 249, 250

Joints, types of, 19

Labour cost, 266
— — saving through suitable design, 267
Lead bronze, oxy-acetylene welding, 120
Leftward welding, 20
Lighting oxy-acetylene flame, 18
Linde welding, 25
Load balancing, resistance welding transformers, 163
Low pressure oxy-acetylene welding, 12
— — blowpipe, 13, 142
— — nozzle sizes for welding steel, 15
— — pressure settings for welding steel, 15

Machine tools, welded, 260
Magnesium alloys, 127
Magnetic crack detection, 244
Maintenance of plant, 223
Malleable iron, 114
Manipulators, 205
— controls, 211
— clamping components, 211
— earthing, 219
— loading capacity, 206, 208, 210
— power requirements, 209, 210
Martensitic structure, 105
Material, list of, 266
Meehanite, 112
Metal-arc welding, 5, 37
— — aluminium alloys, 122
— — automatic, 57
— — cast iron, 114
— — copper alloys, 120
— — deep penetration, 40
— — electrodes, 38
— — electrode classification, 40
— — factors influencing current settings, 57
— — hard surfacing, 116
— — high tensile steels, 109
— — penetration, 39, 240
— — plate edge preparation, 43
— — procedure specifications for welding mild steel, 48–61
— — slag, 39
— — stainless steel, 110
— — technique, 37
— — welding speeds, 57, 268, 269
Ministry of Labour memorandum, 218
Mould for Thermit welding, 72
Multi-spot welding, 95, 215
Mushrooming of spot welding electrode tips, 79

Nelson stud welding, 64, 158
Neutral flame, 16
Nickel-alloy electrodes for welding cast iron, 114
Non-synchroneous timers, 165
Normalizing, 107

Open circuit voltage, 27, 147
— — — for atomic hydrogen welding, 67

Overhead expenses, 266
Overhead welding, 46
— — procedure specification, 56
Oxide film on aluminium alloys, 121
Oxidizing flame, 16
Oxy-acetylene welding, 3, 12
— — aluminium alloys, 122
— — cast iron, 113
— — copper alloys, 120
— — de-oxidised copper, 118
— — equipment, 12, 129
— — flame adjustment, 16
— — gas consumption, 24
— — leftward, 20
— — Linde welding, 25
— — magnesium alloys, 127
— — plant and equipment, 129
— — process and procedures, 12
— — rightward, 21
— — safety precautions, 218
— — speed, 268
— — stainless steel, 110
— — stelliting, 115
— — technique, 20
— — two-operator vertical, 23
Oxy-arc cutting, 200
Oxygen, 129
— consumption, 130
— cutting, 187
— cylinders, 129
— purity, 129, 186

Penetration, 39, 240
Permissible stresses in fusion welds, 238
— — in spot welds, 245
Phase shift control (resistance welding), 85, 168, 179, 182
Pickling material for spot welding, 77, 249
Planning, 250
Plate cutting lay-out, 250
Plate edge preparation, 43
Plate preparation, accuracy, 251
Polarity straight, 28
— reversed, 28
— used in argon-arc welding, 36
Porosity, 103
— in aluminium welds, 123, 124
— in copper welds with carburizing flame, 119
Portable spot welder, 97
Positions for fusion welding, 46
Positioners for welding, 46, 205
Post heating, 107
— — copper, 119
— — malleable iron, 114
— — stainless steel, 109
Power demand (resistance welding), 124, 163
Precision machinery, welded, 259
Preheating, 106, 107
— aluminium alloy castings, 122
— castings for bronze welding, 115
— cast iron, 113
— cast steel, 112
— flame (oxy-acetylene cutting), 188
— for flame cutting high tensile steel, 198
— for hard facing by metal-arc welding, 116
— indirect, 113, 231
— magnesium alloy castings, 127
— replaced by high welding current for first run (aluminium alloy castings), 123
— separate blowpipe for copper welding, 119
— stainless steel, 109
— stelliting, 115
Press frame, welded, 258
Pressure control of resistance welding machines, 83
Pressure regulators, 138
Pressure switch (spotwelder), 176
Pressure welding (oxyacetylene), 76
Projection welding, 9
— — aluminium alloys, 125
— — application, 90
— — fixtures, 215
— — machine, 80
— — settings (mild steel), 92–93
— — types of projection, 91–93
Propane flame cutting, 186
Protective equipment, 218
Purity of oxygen, 129, 186

Quenching, 104, 105, 107

Residual stresses, 227
Resistance welding, 8, 76
— — aluminium alloys, 124
— — copper alloys, 120
— — current, 84
— — electronic controls, 85, 166, 179
— — equipment, 163
— — equipment maintenance, 225
— — forging time, 88, 176
— — fixtures, 214
— — heat equation, 77
— — high tensile steel, 107
— — phase shift control, 168, 179, 182
— — preparation of material surfaces, 77, 249
— — stainless steel, 111
— — strength of joints, 244

Resistance welding timing control, 86
— — timing devices, 165
— — transformer, 85, 163
— — welding time, 88, 176
Respirators, 220
Rightward welding, 21

Safety precautions, 218
— — acetylene cylinders, 139
— — acetylene generators, 134
— — carbide containers, 131
— — clamping components on manipulators, 211
— — oxygen cylinders, 129, 130
Scissors effect, 232
Screens (arc welding), 221
Screening of arc welding points, 221
Seam welding, 9
— — aluminium to steel, 125
— — electronic controls, 182
— — machine, 82
— — settings (aluminium alloys), 125
— — — — (mild steel), 90
Shot blasting material for spot welding, 77, 249
Silicon–aluminium electrodes, 123
— — filler rods, 121
Single stage pressure regulator, 140
Slag, metal-arc welding, 39
— — — removal, 39, 243
— inclusions, 57, 103, 240, 243
— Thermit welding, 73
— traps, 242, 243
Sleeves, 220
Sludge, 130, 134
Spacing of spot welds, 88
Spatter, 243
— protection from, 214
Spot welding, 9, 77
— — aluminium alloys, 124
— — aluminium to steel, 125
— — current adjustment, 176
— — current density, 77, 88
— — electrode tip diameter, 77
— — fixtures, 215
— — high tensile steel, 109
— — indentation, 77, 249
— — machine, 78
— — — control circuit, 175, 179
— — magnesium alloys, 127, 128
— — pliers, 98
— — portable equipment, 97
— — special devices, 95
— — special purpose machines, 98
— — specific pressure, 88
— — test pieces, 101
— — typical settings (mild steel), 88
Spot welds, edge distance, 89
— — spacing, 88
Stack cutting, 196
Staggered welding, 230
Stainless steel, 109
— — argon-arc welding, 110
— — atomic hydrogen welding, 110
— — corrosion, 111
— — flame cutting, 200
— — for good weldability, 112
— — metal-arc welding, 110
— — oxy-acetylene welding, 110
— — preheating and postheating, 109
— — resistance welding, 111
— — weld decay, 112
Stelliting, 115
Step back welding, 231
Stiffeners, removal after heat treatment, 260
Storage of electrodes, 224
Stored energy resistance welding, 124, 128, 164
Strength of welds, 237
— — — influence of plate accuracy, 251
Stresses internal, 106, 227, 233
Stresses in welds, dependable, 238
— — — permissible, 238
— — spot welds, permissible, 245
Stress raisers, 234
Stress relieving, 234
Stud welding, 64
— — equipment, 157
Submerged arc, 64
Supervision of welders, 238
Synchronous timers, 165

Technique, oxy-acetylene welding, 20
— argon-arc welding, 37
— atomic hydrogen welding, 69
— carbon-arc welding, 32
— metal-arc welding, 37
Tensile test of butt welds, 244
Testing of welders, 238
Thermit welding, 6, 71
— — cast iron, 114
— — crucible, 72
— — equipment and technique, 71
— — mould, 72
— — slag, 73
— — used for repair work, 74
Throat section of weld, 237
— thickness of weld, 237
Thyratron, 166
Timing devices (resistance welding), 165
Tin bronze, oxy-acetylene welding, 120
Transformer, arc welding, 30, 155

Transformer atomic hydrogen welding, 160
— maintenance, 224
— resistance welding, 85, 163
Two stage pressure regulator, 141

Unionmelt process, 64
Undercut, 240, 242

Ventilation of welding shops, 218, 220
Vertical welding, 46
— — procedure specifications, 51, 52, 55
Voltage, arc, 27, 146
— arc striking, 26
— drop, 145
— open circuit, 27, 67, 147
— recovery, 27, 145, 148

Warping, 228
Water-flow switch, 83
Water to carbide generator, 132
Welds, 19
Weld decay, 112, 200
Weld gauge, 254
Weldability, 103
Welded construction, advantages and limitations, 1
— — choice by the designer, 2
— — comparison with casting, 1, 264
— — — with riveted construction, 2, 258
Welding, 1
— atomic hydrogen, 6, 67
— blacksmith, 7
— electric-arc, 4, 25
— flash-butt, 10, 94
— helium arc, 4
— means of heat generation, 1
— oxy-acetylene, 3, 12
— projection, 9, 90
— resistance, 8, 76
— resistance butt, 10
— seam, 9, 89
— speeds, 265
— spot, 9, 88
— Thermit, 6, 71
Welding processes, types, 3
Weld positions, 41, 46
Welfare equipment, 218

X-ray examination, 244, 249

Zinc vaporization, 120